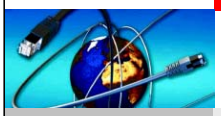
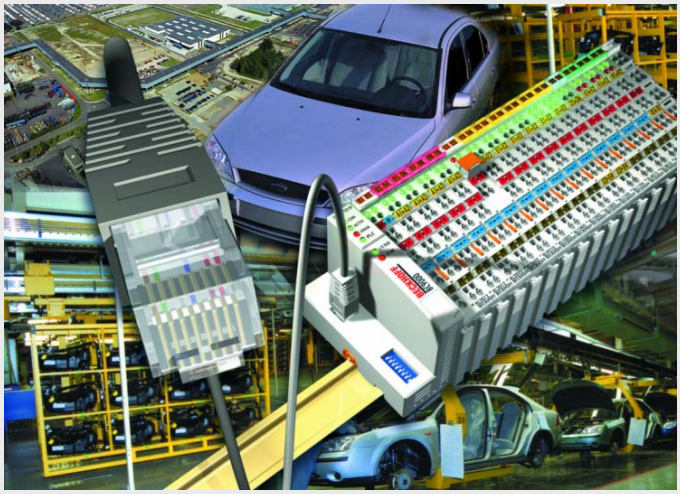


Industrial Ethernet Technologies: Overview

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary



Editorial Preface:

This presentation intends to provide an overview over the most important Industrial Ethernet Technologies. Based on published material it shows the technical principles of the various approaches and tries to put these into perspective.

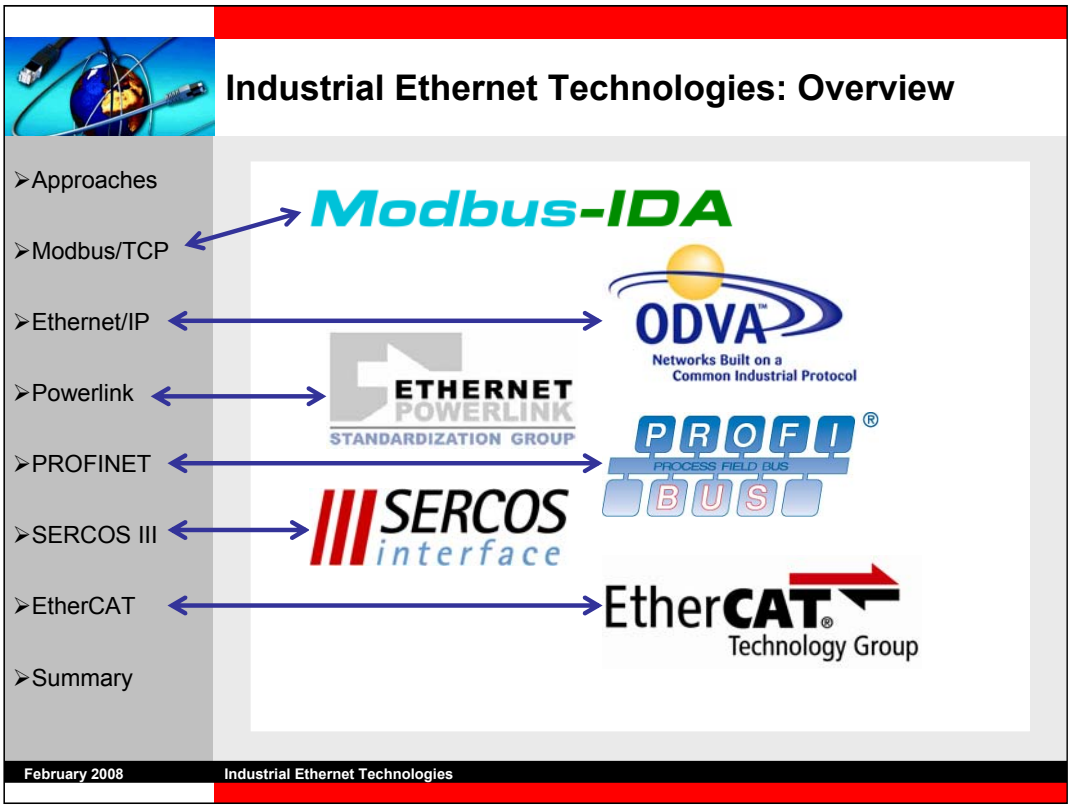
The content given represents my best knowledge of the systems introduced. Since the company I work for is member of ODVA, PNO/PTO, Sercos, ETG and supports all important open fieldbus and Ethernet standards, you can assume a certain level of background information, too.

The slides were shown on ETG Industrial Ethernet Seminar Series in Europe and USA as well as on several other occasions, altogether attended by far more than 1000 people. Among those were project engineers and developers that have implemented and/or applied Industrial Ethernet technologies as well as key representatives of some of the supporting vendor organizations. All of them have been encouraged and invited to provide feedback in case they disagree with statements given or have better, newer or more precise information about the systems introduced. All the feedback received so far was included in the slides.

You are invited to do the same: provide feedback and – if necessary – correction. Please help to serve the purpose of this slide set: a fair and technology driven comparison of Industrial Ethernet Technologies.

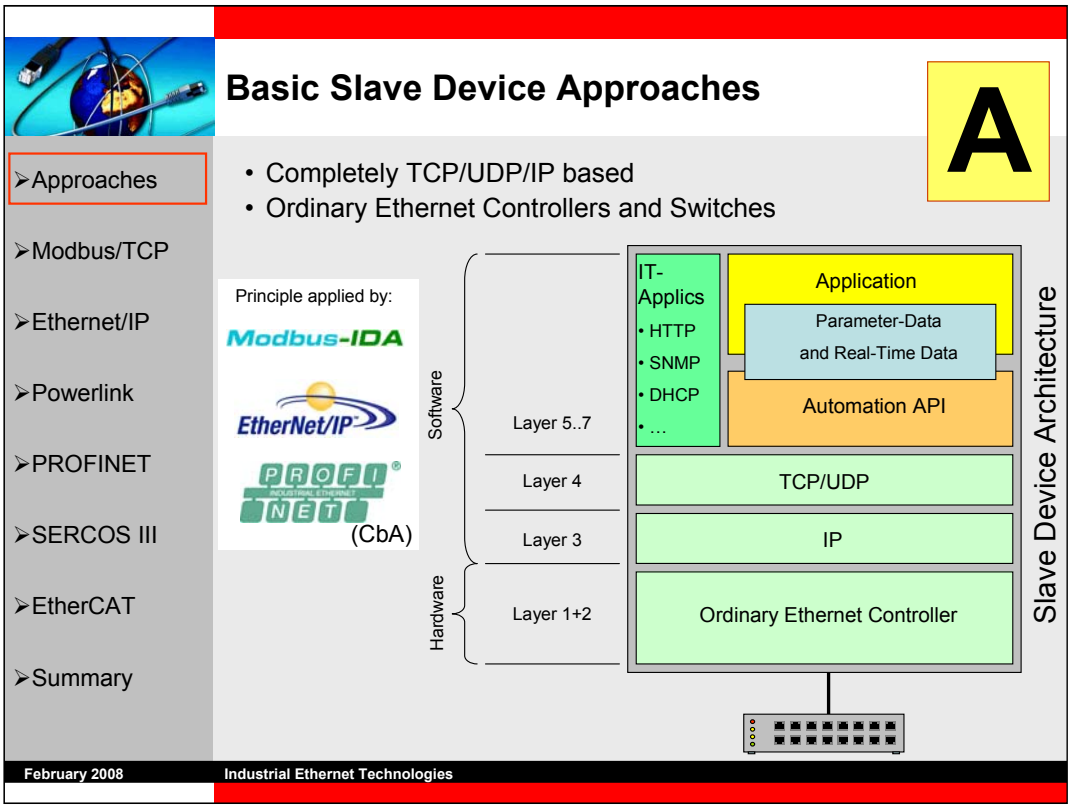
Nuremberg, February 2008

Martin Rostan, m.rostan@ethercat.org



All Industrial Ethernet Technologies introduced in this presentation are supported by user and vendor organizations. EPSG and ETG are pure Industrial Ethernet organizations, whilst the others have a fieldbus background and thus members primarily interested in the respective fieldbus technology.

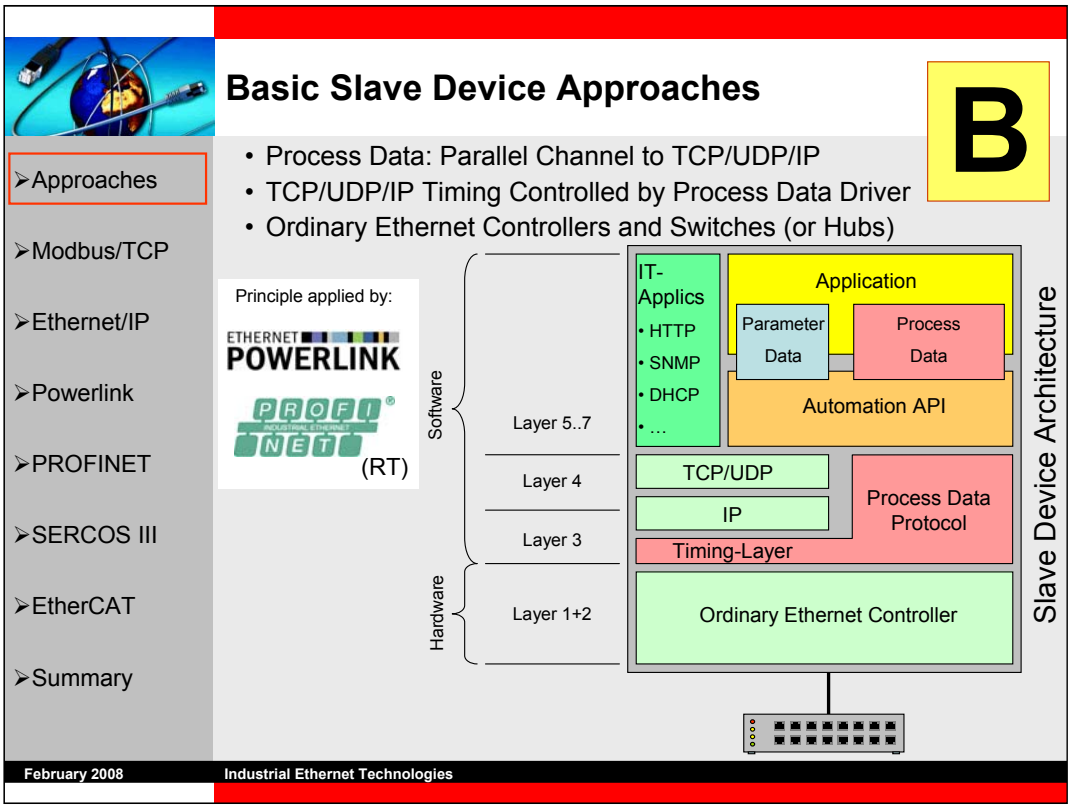
All technology names as well as the names of the organizations promoting and supporting those are trademarked. The trademarks are honored.



Depending on the real time and cost requirements, the technologies follow different principles or approaches. This comparison tries to group those approaches in three different classes by looking at the slave device implementations:

Class A uses standard, unmodified Ethernet hardware as well as standard TCP/IP software stacks for process communication. Of course some implementations may have modified „tuned“ TCP/IP stacks, which provide better performance.

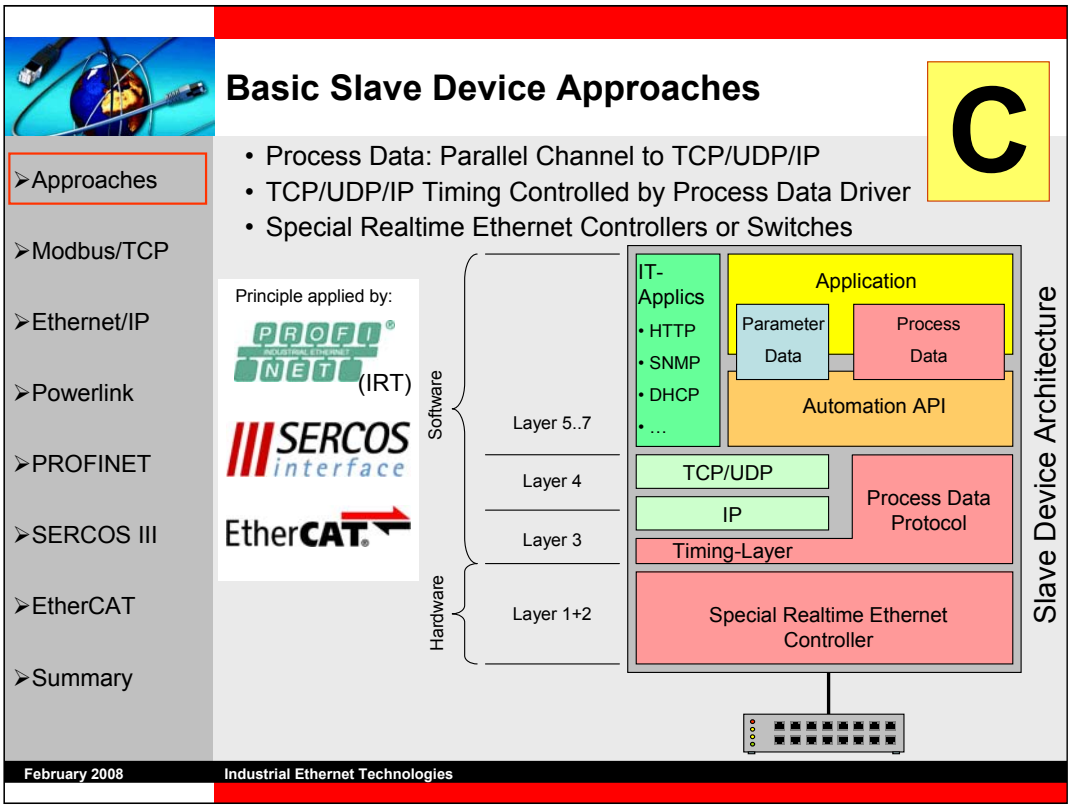
Class A approaches are also referred to as „best effort“ approaches. The real time performance is limited by unpredictable delays in infrastructure components like switches – no just due to other traffic on the network. The by far largest obstacle to better real time performance however is provided by the software stacks (TCP/UDP/IP).



Class B approaches still use standard, unmodified hardware, but do not use TCP/IP for process data communication. A dedicated process data protocol is introduced, which is transported directly in the Ethernet frame.

TCP/IP stacks may still exist, but typically their access to the Ethernet network is controlled and limited by what can be considered a timing layer.

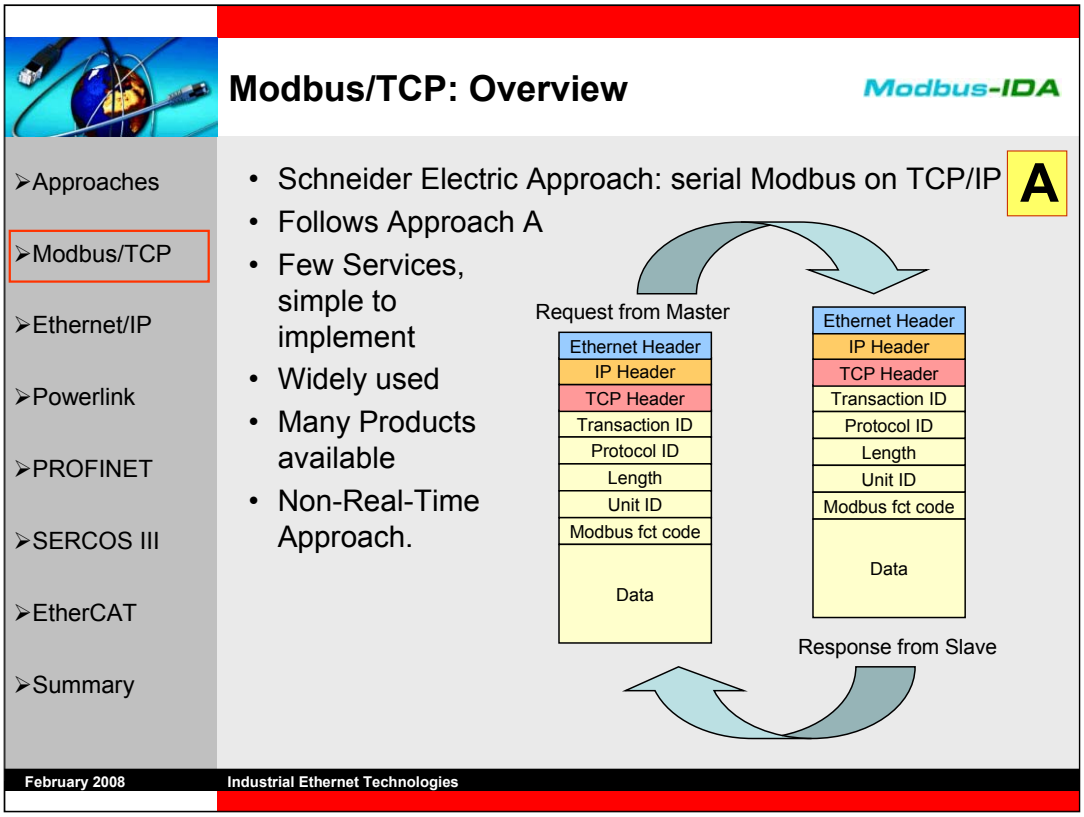
Of course this description is pretty generic – but more details are given in the technology specific sections.



Class C approaches aim even higher with regard to performance. In order to achieve these goals, dedicated hardware has to be used (at least on the slave device side).

In case of Profinet IRT, the Special Real-time Ethernet Controller is more a Special Switch Device – but the result is the same: better performance due to better hardware integration.

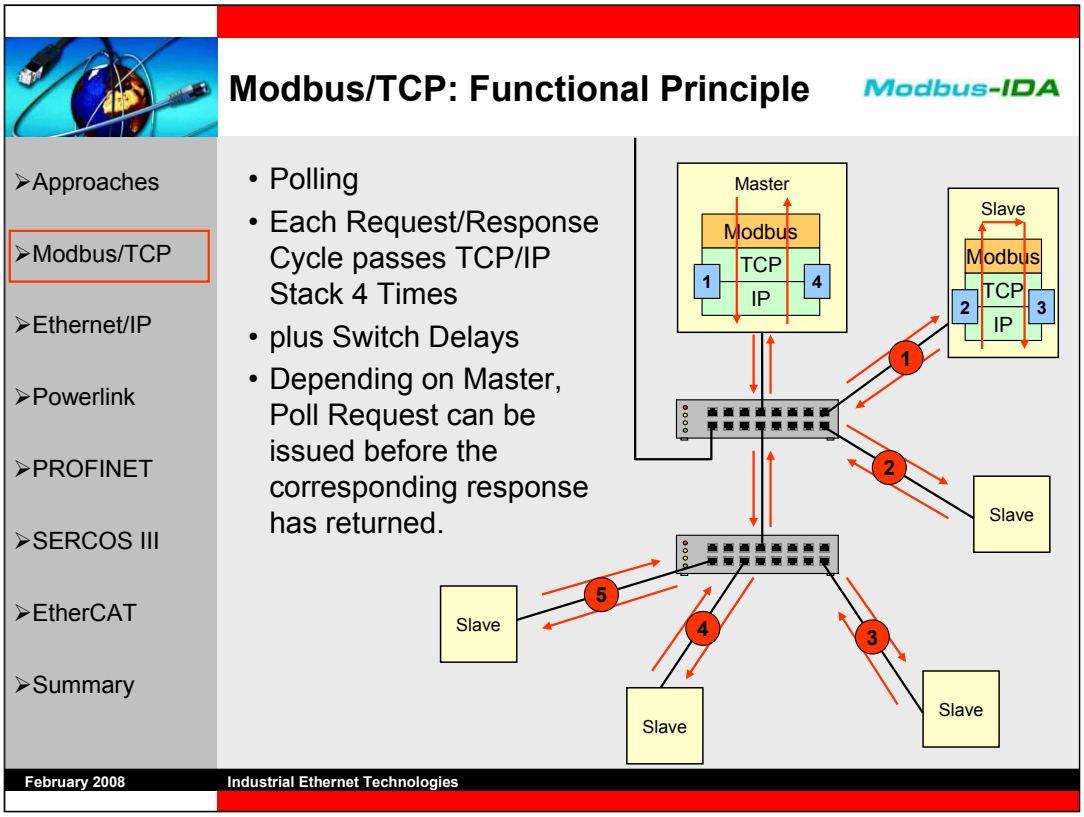
This does not exclude the use of TCP/IP and the Internet Technologies.



Modbus/TCP is very widely used, since it is simple to implement.

Non-real-time approach: Due to its operating principle, Modbus/TCP cannot guarantee delivery times or cycle times or provide precise synchronization. Strongly depending on the stack implementation, response times of a few milliseconds can be achieved, which may be sufficient for certain applications.

Apart from the basic data exchange mechanisms, there is hardly any additional feature. Network management, device profiles, etc. have to be handled by the application program, the network layer does not provide solutions.



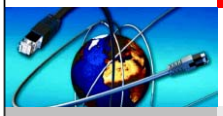
Modbus/TCP master implementations can either wait for each response to return before the next request is issued, or send several requests at once in order to allow for parallel processing in the slave devices. In the later case the overall performance is improved.

Since the performance is primarily determined by the stack performances, it very much depends on the implementation of the master and slave devices – which is difficult to assess.

If a master is implemented on a standard socket interface of a Windows OS, typical response times (per slave) are in the order of 10-20ms with a worst case (e.g. moving a Window) of well over 250ms (We have tested this. The reason is that the OS processes the TCP/IP stack with low priority). Of course it is possible to implement a master with an RTOS and/or using a dedicated communication CPU and achieve better results.

A slave device with sufficient processing power and an optimized (=functionally reduced) TCP/IP stack may typically reply within 1-4 ms (and in worst case, depending on the load, within 10-15ms). Standard TCP/IP stacks on µC may have typical response times of >5ms.

Critical can be the retry times of the TCP/IP stacks – in case a frame was lost. These retry times can be in the order of seconds – and typically are not user definable nor mentioned in the product manuals.



Modbus/TCP: Future?

Modbus-IDA

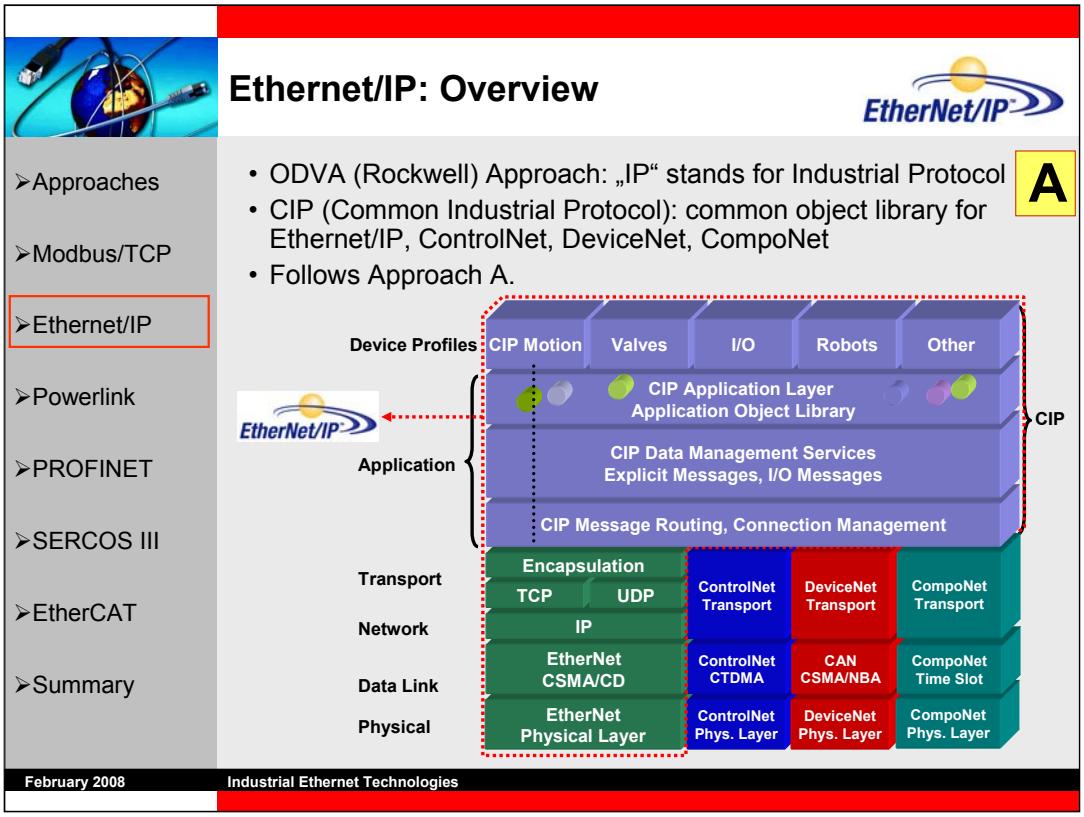
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- In April 2007, Schneider Electric joined ODVA as principal member and announced Ethernet/IP products for 2008.
- ODVA announced „*to provide compatibility of Modbus®/TCP devices with networks built on CIP*"
- A "Modbus Integration SIG" was established to specify the "CIP to Modbus Translator"

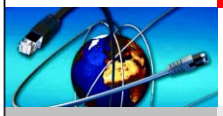
- Future of Modbus/TCP looks uncertain, since driving force seems to walk away

Modbus/TCP will certainly not vanish any time soon, but this move of Schneider indicates that there will not be enhancements or maintenance of the protocol.

Schneider replaces one non-real-time protocol by another one.



Ethernet/IP claims to use the same application layer as Devicenet, Controlnet and CompoNet. This may be beneficial for those that are familiar with those fieldbus networks. However, taken from the experience when implementing Devicenet and Controlnet, the synergy effects are expected to be somehow limited, since the communication technologies and even the protocols differ substantially.



Ethernet/IP Functional Principle

EtherNet/IP

- Approaches
- Modbus/TCP
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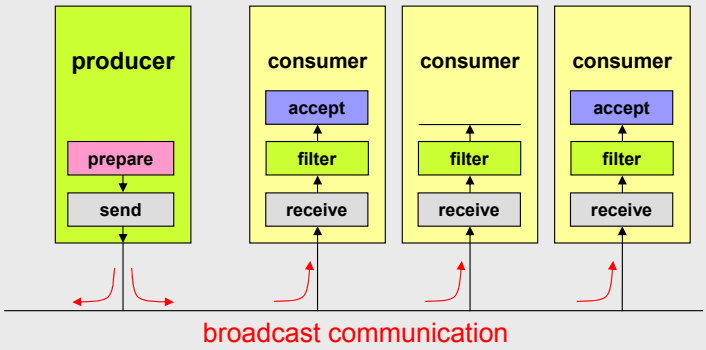
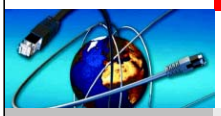
- Summary

Consumer / Producer Model

- Advantage: very efficient for slave-to-slave Communication
- Disadvantage: requires Broadcast communication and thus filtering in each device



By applying broadcast or multicast communication, the switches cannot forward incoming frames to a single destination port only - so they act like (full-duplex) Hubs, but with larger delay.



Ethernet/IP Switch + Router Issues

EtherNet/IP

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

CONCLUSIONS

In this paper, we have characterized the EtherNet/IP™ traffic and provided recommendations aimed to optimize network, and ultimately control system, performance. These recommendations are based on utilization of switching devices in the EtherNet/IP™ infrastructure that possess specific features, like IGMP Snooping, aiming to minimize end-device and switch loading with unwanted traffic as well as propagation of the such a traffic to and from a plant network.

ISSUES

The following issues have been identified during performance and interoperability tests of EtherNet/IP™ products performed by Rockwell Automation:

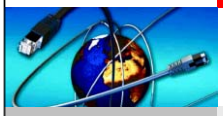
- Inconsistency of IP multicast control features (what they do and how they work) between network switch vendors and in some cases even between different classes of products produced by the same vendor.
- Lack of IP multicast control, support of the IEEE 802.3 spanning tree protocol and other appropriate features in some low-end switches, which considerably limits their use in non-isolated EtherNet/IP™ networks.
- Lack of industrial high-end Layer 2 and Layer 3 switches.

from a technical paper found on the ODVA website

This paper by Anatoly Moldovansky, a senior engineer from Rockwell Automation (and a nice guy!), highlights some of the issues with Ethernet/IP: there is a need for routers with multicast/broadcast control features, and there is no standard way to implement or configure these.

IGMP snooping constrains the flooding of multicast traffic by dynamically configuring switch ports so that multicast traffic is forwarded only to ports associated with a particular IP multicast group.

Furthermore, high-end switches typically have high-end prices. Rockwells documentation states that switches for Ethernet/IP have to support IGMP snooping as well as port mirroring (for troubleshooting). They should also support VLAN and SNMP – so manageable switches are required.



Ethernet/IP Topology

EtherNet/IP

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
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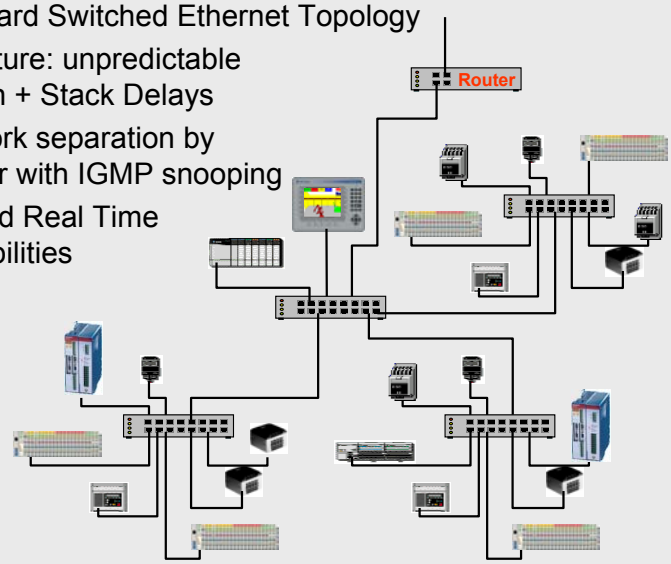
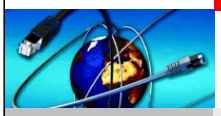
- SERCOS III
- EtherCAT
- Summary

- Standard Switched Ethernet Topology
- By nature: unpredictable Switch + Stack Delays
- Network separation by Router with IGMP snooping
- Limited Real Time Capabilities



Even though the switch delays are unpredictable by nature, the delays introduced by the software stacks are much more significant.



Ethernet/IP Performance

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- **Rockwell implementation allows few connections (1 – 32)**
- **Minimum Cycle Time (RPI; Requested Packet Interval) is dependent on number of connections**
- **Each Device can have multiple Connections**

min_RPI = (number of connections x 2) / (no. of frames/second)*

* (assumed all connections request same "RPI" scan time).

No. of Connections	Min_RPI (ms) with 5000 Frames/sec
4	1,6
8	3,2
16	6,4
32	12,8

Ethernet/IP distinguishes CIP and TCP Connections. Whilst most Rockwell Ethernet/IP devices support up to 64 TCP connections, the number of CIP connections differ from device to device.

For communication with an I/O device, typically more than one CIP connection is used (e.g. one for implicit messaging, one for explicit messaging).

According to the Rockwell publication „Ethernet/IP Performance" (ENET-AP001D-EN-P, released October 2004, according to RA website still valid in January 2008) there are no Rockwell devices that support more than 32 CIP end-node-connections. Some support more CIP connections, e.g. for additional bridged connections that pass through the EtherNet/IP module.

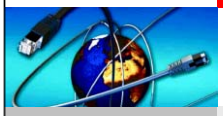
For more detailed information regarding Ethernet/IP performance please check the Rockwell publication mentioned above (and corresponding updates), available for download on the internet. There one can see also the complexity of a performance prediction for an Ethernet/IP network – and the need for multiple scanner cards in one controller. For an example system with just 5 I/O stations and two scanner cards in the host controller the maximum input delay was calculated with 32.5ms.

Lack of CIP connections can be a problem: even in small networks one may not be able to connect a PC for configuring the PLC since this would need too many connections.

In November 2006 RA announced a new generation of Ethernet/IP scanners which will support up to 10.000 frames/second. With these new scanners the cycle times in the table above will be half as long – and thus system real time performance will remain relatively poor.

However, the latest release notes (Publication 1756-RN591P-EN-P - June 2007) of the Contrologix Ethernet IP Bridge (1756-ENBT) contain the following passage:

Performance Considerations: *In general, the 1756-ENBT module is capable of supporting 5,000 packets/seconds. However, it is possible in some applications, depending on the combination of connection count, RPI settings, and communication formats, that the product may be able to achieve only 4,000 packets/seconds.*

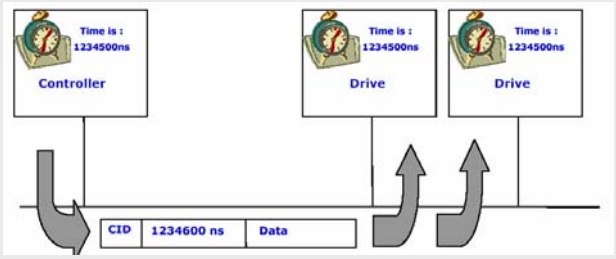


Ethernet/IP + CIP Sync

EtherNet/IP™ CIP Sync™

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

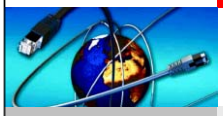
- Ethernet/IP has limited Real Time Capabilities:
  - limited Cycle Time Performance, limited Determinism
  - acceptable Throughput (for large Data Units)
- CIP Sync will add Time Synchronisation
- Distributed Clock Protocol: IEEE 1588
- CIP Sync: announced April 2003, Added to CIP spec in May 2006 (Version 3.0). First products expected for 2008.



CIP sync was introduced to improve the real time behavior of the system.

The marketing message given by ODVA tries to tell that by adding synchronization the real time capability is achieved – but time synchronization does not improve cycle time, throughout or performance.

CIP sync was announced in April 2003, and included in Version 3.0 of the CIP spec in May 2006.

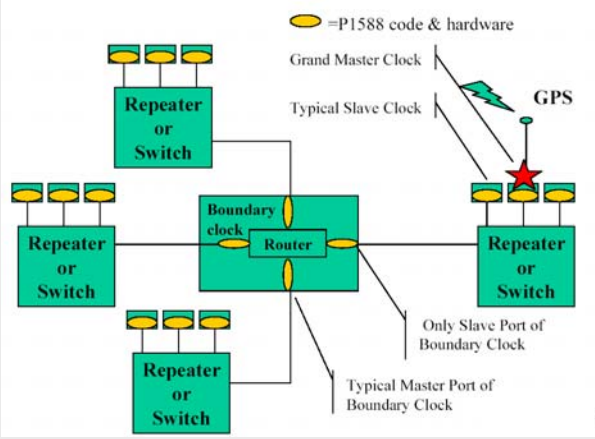


What is IEEE 1588

CIP Sync

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- A method for precision time synchronisation (widely protocol independent) tailored to requirements of distributed measurement and control systems
- If applied to Ethernet: based on UDP/IP (as of today…)



Source: introduction_to_1588.pdf by IEEE

IEEE 1588 is a protocol for time synchronization that is or will be used by a variety of systems: Ethernet/IP, Profinet, Powerlink,... EtherCAT will also support external time synchronization with IEEE1588.

Interoperability is improved by regular plug-fests.

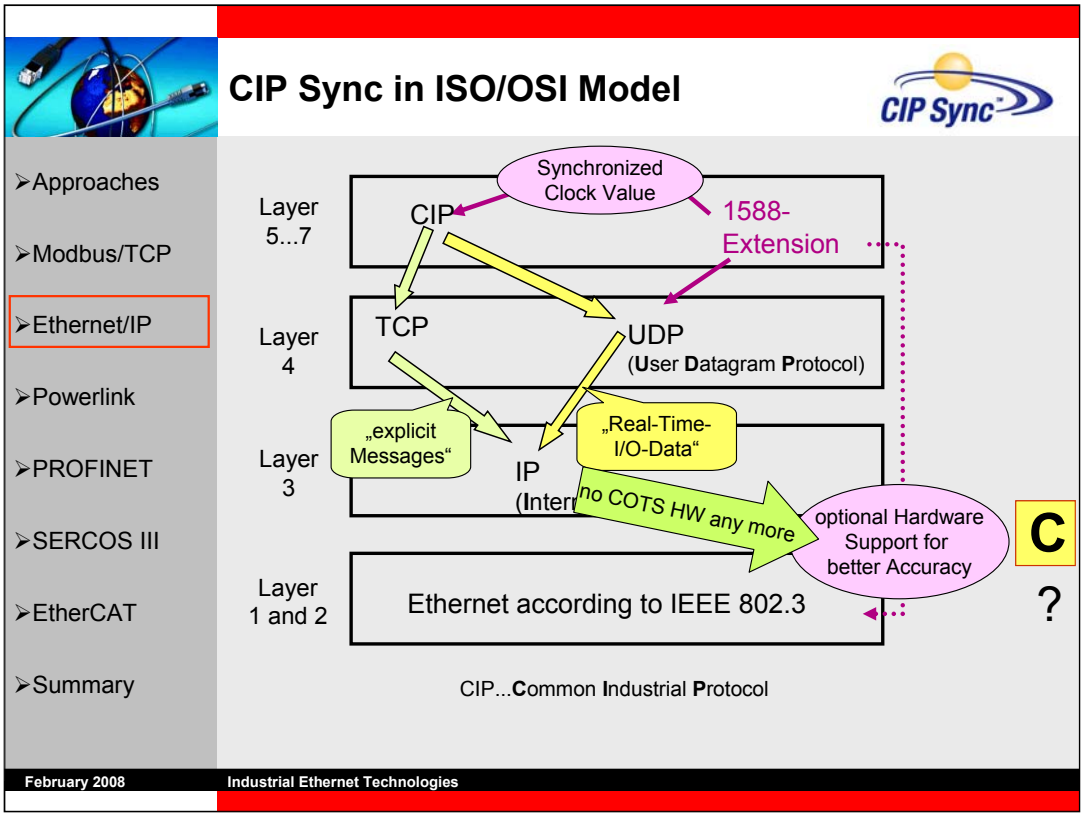
IEEE 1588 is a published standard, but the technology is currently being modified or enhanced by a study group. This is one reason why some vendors have postponed their implementation. It is the goal that the resulting protocol varieties will be interoperable. Hopefully they will be supported by all implementations (hw+sw)

So far there are few known (if at all) automation applications using this technology, adoption rate is slower than expected initially.

Since the Ethernet implementation of the standard uses UDP/IP, stack processing times limit the accuracy in case of pure software implementations. It is possible, however, to achieve good results by employing chips (and switches) with built in IEEE1588 support – first silicon has been introduced by Intel and Hyperstone. One can argue if these can be considered “standard Ethernet Chips”.

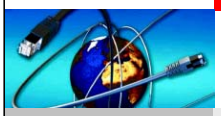
Just to clarify this one: No objections to use special hardware in order to achieve better real time behavior or reduce costs. But then this should be clearly stated.

IEEE 1588 will almost certainly be an important time synchronization protocol, but as of today, it is not yet.



In order to make the time synchronization independent from software jitters and stack performance, at least the time stamp functionality had to be implemented in hardware (directly in or at the Ethernet MAC).

This will turn the class A approach “Ethernet/IP” into the class C approach “Ethernet/IP with CIPsync”.



Ethernet/IP + CIP Sync

EtherNet/IP™ CIP Sync™

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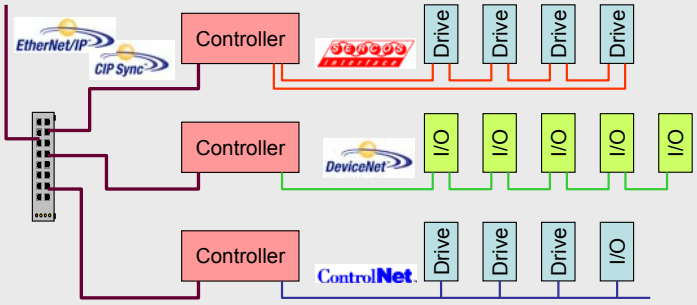
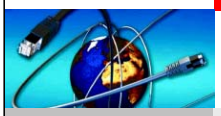
Best suited and typically used as Controller to Controller network

- Limited No. of Connections
- Bus cycle time is typically 5 .. 10 ms
- Reaction time is typically 15 .. 30 ms
- Determinism is added via system-time-synchronized actions and timely non-deterministic communication.



Example Ethernet/IP Network

Even though it is more and more used for I/O communication as well, the nature of Ethernet/IP clearly shows that this technology is aimed at the controller to controller level. The synchronization capabilities of CIPsync are suitable for synchronizing motion controllers, but the communication performance is not sufficient for closed loop servo drive communication.

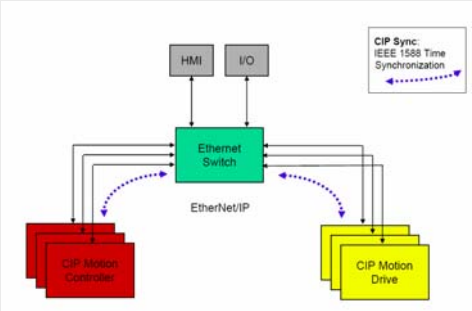


CIP Motion + CIP Sync

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

Initiative of ODVA to enhance CIP networks for motion control

- Ethernet/IP Premise: Full duplex, switched Ethernet with QoS Prioritization, IEEE 1588 Synchronization and time stamped data transmission is deterministic enough for motion control
- Motion Control Device Profiles included in V3 of CIP Spec
- First products expected for 2008
- Even though closing control loop over bus system will be part of spec, limited performance of Ethernet/IP leads to trajectory generator in drive
- Same approach as with legacy non-motion fieldbus systems



February 2008 Industrial Ethernet Technologies

Beginning of 2006, ODVA announced an initiative to enhance the CIP protocols by CIP Motion for motion control over Ethernet/IP.

ODVA acknowledges that three main ingredients are required:

Synchronization services: for this purpose IEEE1588 time synchronization (CIP Sync) will be employed

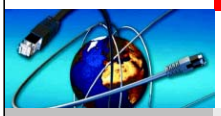
Timely Data Transfer: The goal is to use standard Mechanisms to insure this:
- Full-Duplex 100-BaseT or 100BaseF “Fast” Ethernet.
- Ethernet Switches to Eliminate Collisions.
- QoS Frame Prioritization to Eliminate Queuing Delays

Motion Control Device Profiles: have been added in V3 of the spec.

The goal is to achieve high-performance motion control over standard, unmodified, Ethernet.

Even though ODVA aims to achieve timely data transfer in the sub-millisecond cycle time range, this is in total contradiction to the “real life” Ethernet/IP performance. It may be possible to achieve sufficient results in very small, isolated and well engineered networks with carefully selected components. But real life applications will almost certainly be limited to open loop motion control with the trajectory generator in the drive – which is also possible with legacy fieldbus systems like DeviceNet. Whilst the CIP Motion Device Profile is mapped to Ethernet/IP only (and not to DeviceNet, ControlNet), most parameters and mechanisms of the profile clearly have been included to compensate for lack of short cycle times: they describe local trajectory generation. Compared to other drive profiles of IEC 61800-7, the profile is therefore rather complex.

It is interesting to note that this announcement seems to imply that Rockwell – a Sercos vendor in the past – has turned down Sercos-III and tries to push an own motion bus approach.



Ethernet/IP Summary

EtherNet/IP

- Approaches
- Modbus/TCP
- Ethernet/IP
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- Summary

Conclusions:

- Network made for many Bytes of information per connection
- Not intended for Drives and I/O (Bit-sized connections)

Technical Issues:

- Performance not convincing („use ControlNet“)
- Ethernet/IP uses broadcast telegrams
- requires complex router configuration (e.g. IGMP snooping) to avoid frame flooding of connected manufacturing and corporate networks
- Filter algorithm implementations differ within switches, therefore IT specialist may be needed in real life situations

Strategic Issues:

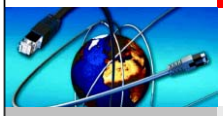
- Relatively slow adoption rate outside Rockwell world

A quote from a Rockwell employee: if you need more performance, use Controlnet...

Adoption rate: as of Oct 2007, more than 6 years after publication of the spec, the ODVA website lists 62 “non Rockwell”- product guide entries (82 alltogether), out of which 23 are switches, cables and connectors.

However, Rockwell / ODVA started to work on this in 2006, since Profinet and EtherCAT have arrived: there are lots of implementer workshops and training classes now.

For comparison: 3 years after publication of the spec, the ETG website lists 79 “non-Beckhoff” product guide entries (112 alltogether).



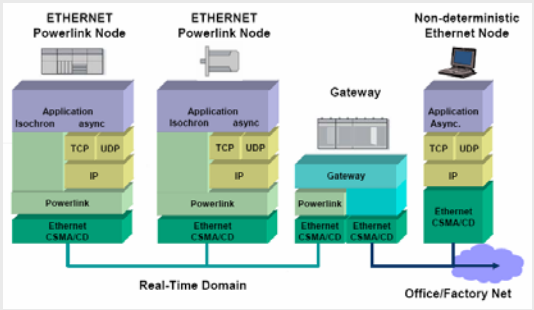
Powerlink: Overview

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

B

- Ethernet Approach originally introduced by B+R
- Medium Access Control by Polling (similar to Profibus)
- TCP/IP for Parameters, seperate Process Data Protocol
- uses Hubs (no switches)
- active Master Plug-in-Card required, no Standard NICs
- hard realtime mode + soft realtime („open“) mode (V3, initially announced for 2005)



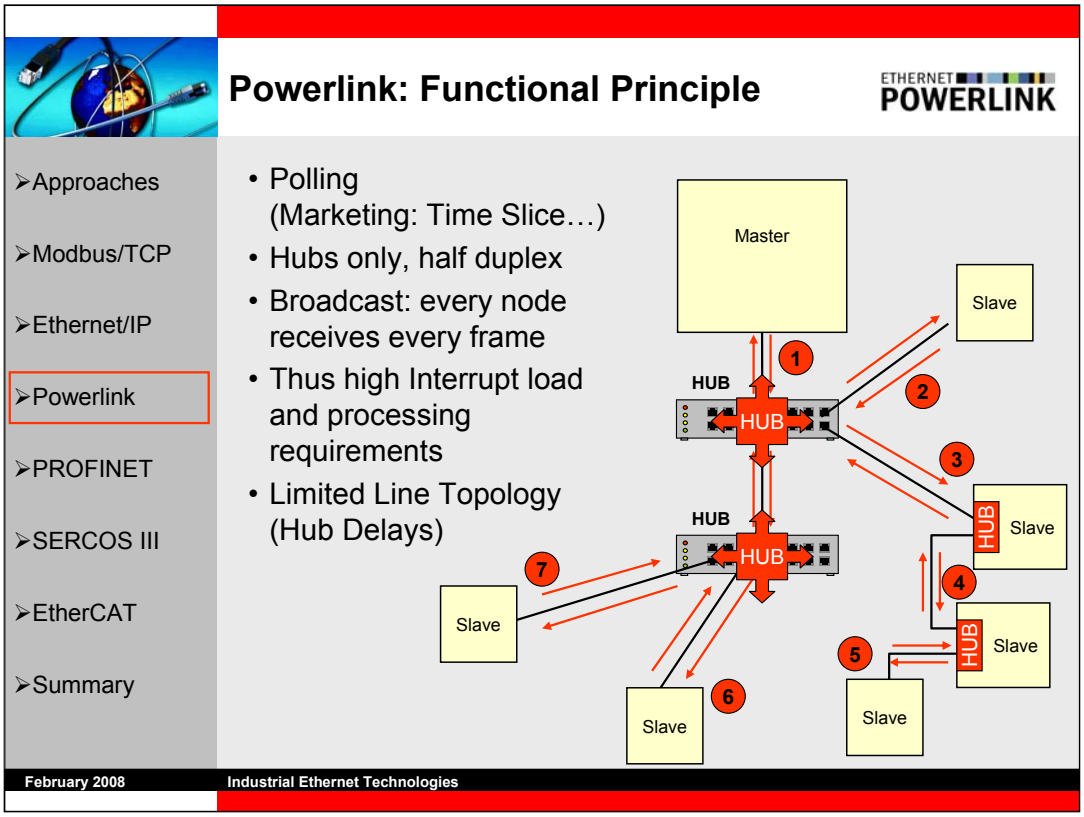
Powerlink replaces the Ethernet CSMA/CD Media Access Control Method by Polling: The master (called managing node) sends a poll request to each slave (called controlled node) which then answers with a response.

Hubs (no switches): the Powerlink Spec states: „To fit EPL jitter requirements it is recommended to use hubs“*.

Protected real time mode: Since the Powerlink topology (up to 10 nodes in line configuration) violates IEEE802.3 roundtrip delay rules, CSMA/CD does not work in this configuration – so a network designed for protected mode cannot be accessed with standard Ethernet interfaces (not even in non-realtime mode).

* In theory switches can be used, but due to the additional latency the network performance would be unacceptable. All performance calculations in the Powerlink spec assume a Hub Delay Time of 500ns – „store and forward“-switches have a delay time of >10µs (for short frames), „cut through“-switches have a delay time (according to Intel) of ~7,5µs. If hubs were replaced by switches with 10µs delay, the cycle time of example 4 in the Powerlink Spec would be increased from 2,34 ms to 19,44 ms.

In September 2005, EPSG announced that Micrels new 3-Port switch chip is endorsed for Ethernet Powerlink implementations. However, in Powerlink applications this switch chip is operated in half duplex repeater mode, only. Thus it is a switch chip that supports a hub mode, too.

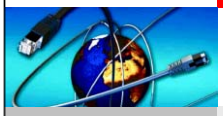


Powerlink Marketing calls the Media Access Method „Time Slicing“ or „Slot Communication Network Management“. The principle nevertheless is polling – the controlled device only „speaks“ after it was „asked“.

Due to the broadcast nature of hubs, all nodes receive all frames. Therefore the nodes have to filter each frame.

The broadcast mechanism can be used for slave to slave communication (consumer/producer principle). However, performance of slave to slave communication cannot be better than the cycle time...

The accumulation of the hub delays limits the number of nodes in a line topology.

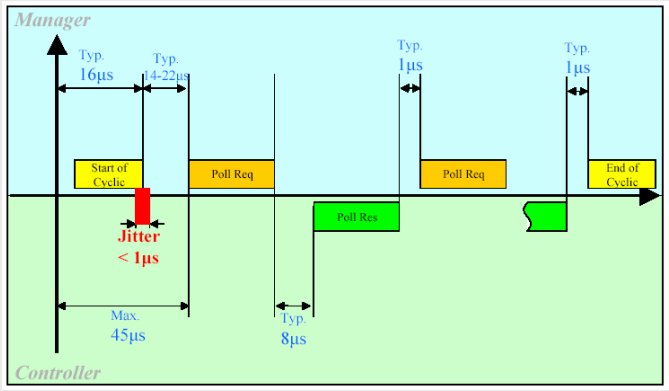


Powerlink Timing

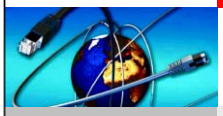
ETHERNET POWERLINK

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Overall Network Performance depends on Slave Implementation:
- Fast response time requires powerful processors on the slave (controller) side – or implementation in Hardware (FPGA)
- A lot of „idle time“ on the media



The diagram is misleading: A typical poll response (up to 46 Bytes of data) is 7µs and thus shorter than the typical response delay time of a slave device. Or, in other words, the idle time on the half duplex media is even longer than indicated.



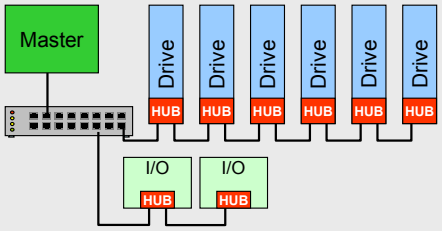
Powerlink Performance

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

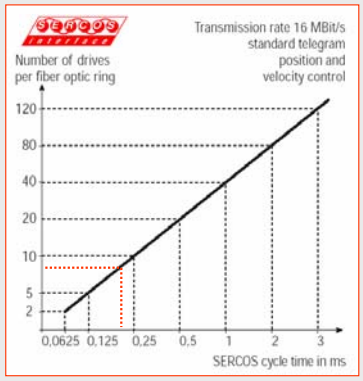
Application Example:

- 6 Drives
- 2 I/O Nodes
- 400 m Cable Length
- Cycle Time: 291 µs

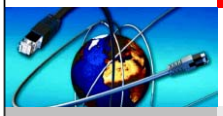


For Comparison:

- Sercos II (16 Mbaud): < 250 µs
- EtherCAT: 17 µs.



The performance examples are taken from the Powerlink spec Version 2. There a Powerlink slave response time of 8µs and a master response time of 1(!) µs are assumed.



Powerlink Interface Costs (I)

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
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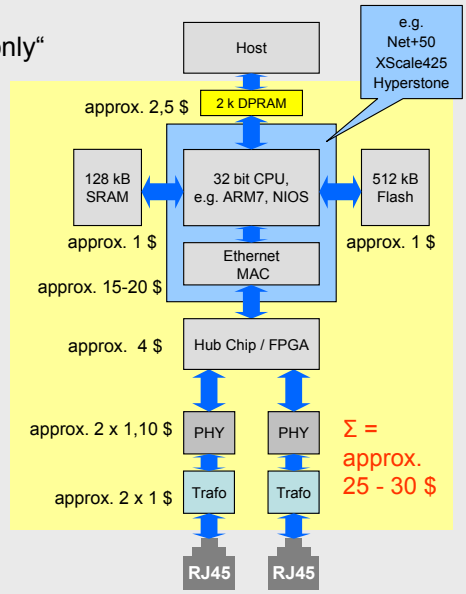
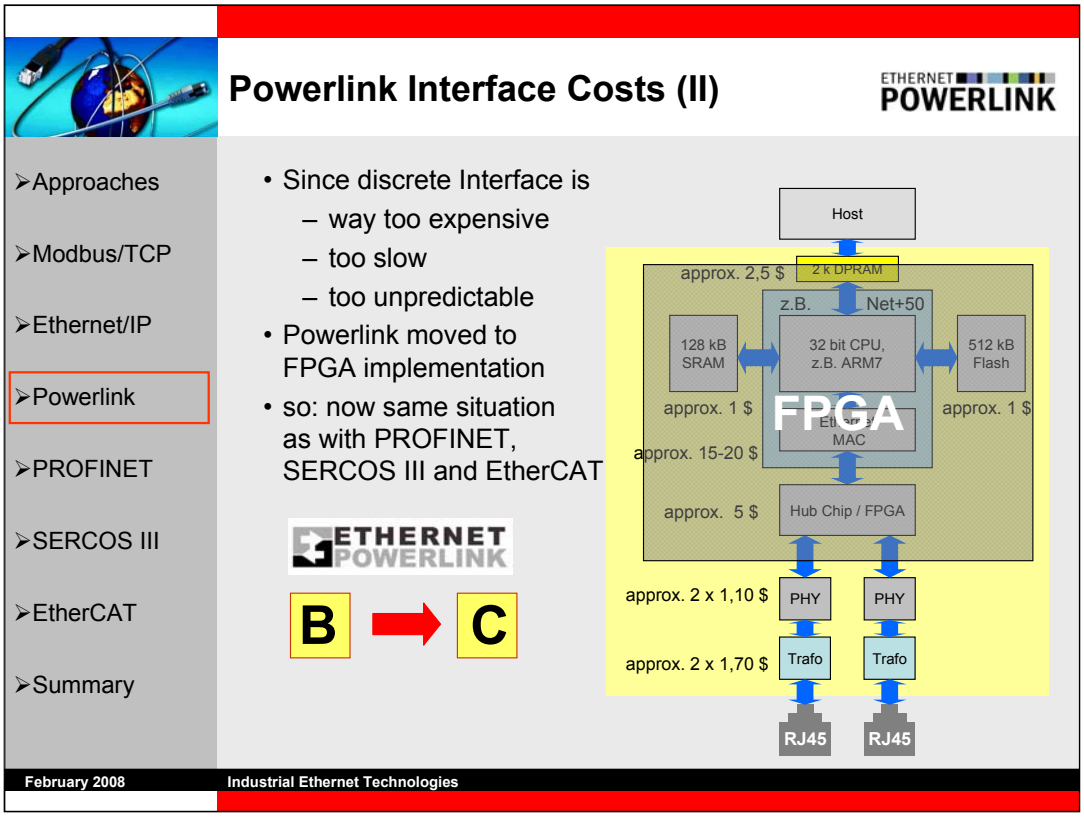
- EtherCAT
- Summary

- Powerlink claimes to use „standard Ethernet chips only“
- But: Hub Chips become obsolete -> ASIC or FPGA required
- Nodes need a 32 bit CPU and infrastructure
- Total cost for the interface, made of „standard Ethernet chips“: around 25 to 30 $.



This hardware block diagram was drawn by an EPSG member company and shows the hardware effort for a Powerlink interface based on standard chips. The chip costs listed may be outdated meanwhile, but it remains valid that the discrete design of a Powerlink slave interface is not a very cost efficient approach.

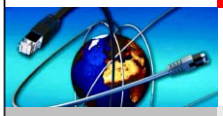


EPSG has announced different implementation possibilities – the most cost effective is the FPGA solution. It uses the same Altera FPGA that is used for EtherCAT as well, but requires additional 10ns 256k x 16 SRAM.

In November 2007, IXXAT, B&R + Lenze announced that the master (managing node) will now also be implemented in an FPGA.

The rationale is, according to a press statement*: "*Until now on the control side there were only solutions which had limited performance and which were not suitable or too expensive for extremely demanding applications such as highly dynamic motion systems, since very powerful CPUs are used*."

* Translated from the Article "Master-FPGA für Powerlink", Computer&Automation Magazine 12/2007, p.17



Powerlink: Time to Market

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
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- Powerlink
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- EtherCAT
- Summary

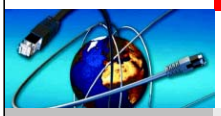
Network Version	Feature	Availability
Powerlink Version 1	• **Protected mode**	**Available by B&R only**
Powerlink Version 2	• **Enhanced initialization** • **Configurable asynchronous channel** • **Complete TCP/IP implementation** • **Bridge / Router Support**	**Spec: Q4 / 2003** • **First prototypes: HMI 2004** • **No Pilot applications published yet** *** Not compatible to version 1**
Powerlink Version 3	• **Open mode** • **IEEE1588 synchronization**	**End of 2005??**

Powerlink Version 1 products are available from B&R only.

Powerlink Version 2 Prototypes were announced for Hannover Fair 2004, but the multi-vendor demo was based on V1 prototypes. Those prototypes were not advanced to become V1 products.

In an interview in April 2006, B&R claimed that they were shipping V2 devices since beginning of 2006, which proves my point that the devices in the field are V1. As of July 2006, none of the B&R applications with V2 has been published yet. According to well informed sources, in April 2007 B&R was still shipping V1 devices only– and is thus incompatible with any product developed by other EPSG member companies.

At Hannover Fair 2006, Lenze Drives (founding member of Ethernet Powerlink Standardization Group and driving force behind V2) has announced first Powerlink Products for End of 2006. At the same show, Lenze has announced EtherCAT drives.



Powerlink Versions

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
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- EtherCAT
- Summary

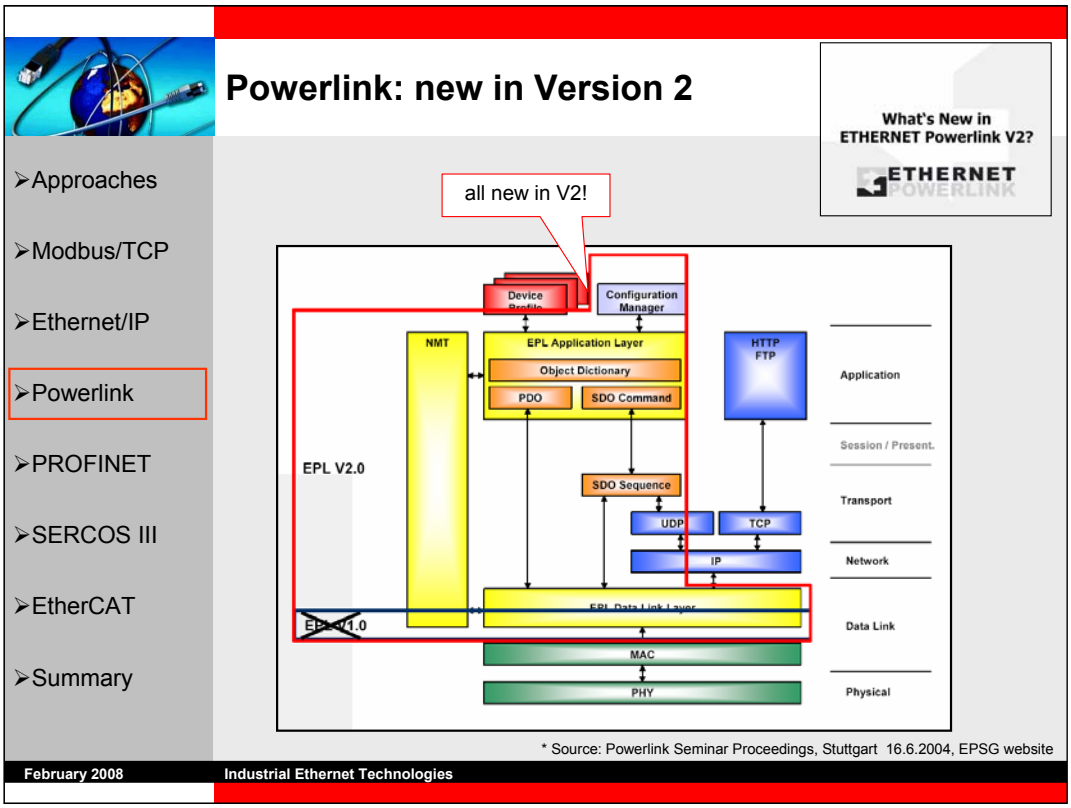
ETHERNET POWERLINK STANDARDIZATION GROUP

Roadmap

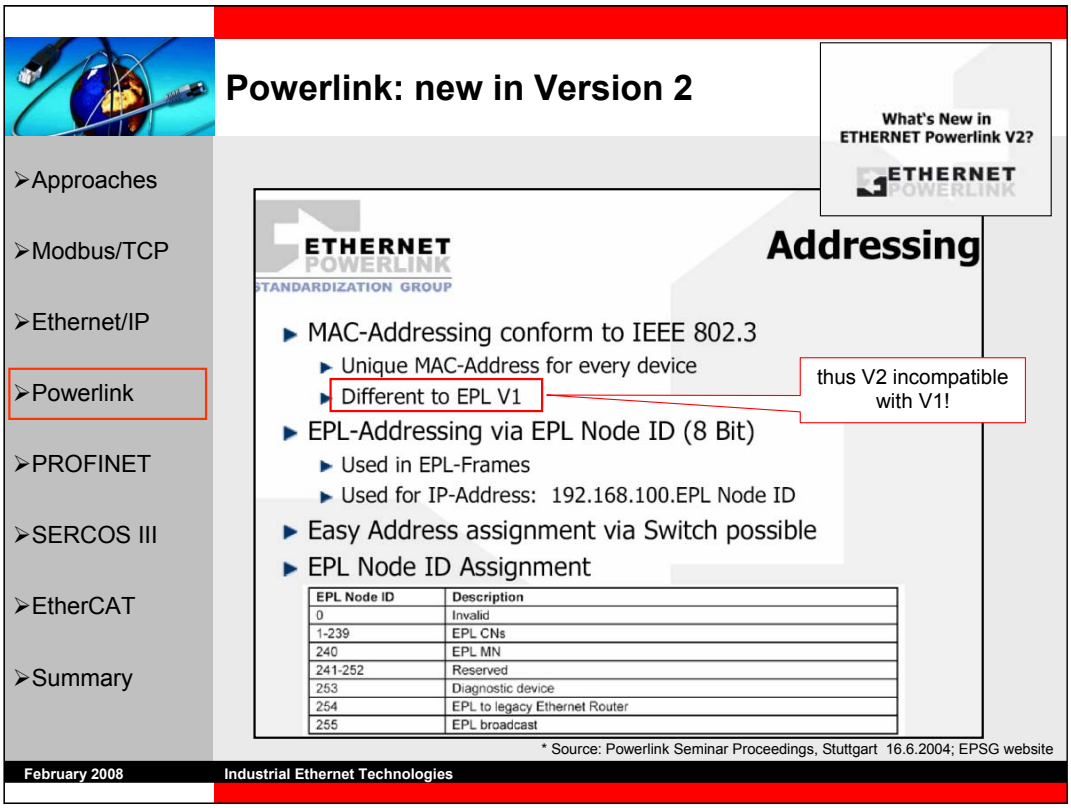
- Version 1 – available
  - Protected mode
  - >15.000 nodes deployed in serial machinery
- Version 2 – Dec 2003
  - CANopen integration
  - Enhanced initialisation
  - Configurable asynchronous slot
  - Full TCP/IP support
  - Routing
  - Security
  - First products at Hannover Messe 2
- Version 3 – 2004
  - Open mode
  - IEEE 1588

* Source: Powerlink Seminar Proceedings, Stuttgart 16.6.2004; EPSG website

This slide, found at the EPSG website in 2004, shows the Roadmap – and proves that the first nodes shipped in quantities were Version 1. Version 3 was postponed meanwhile.



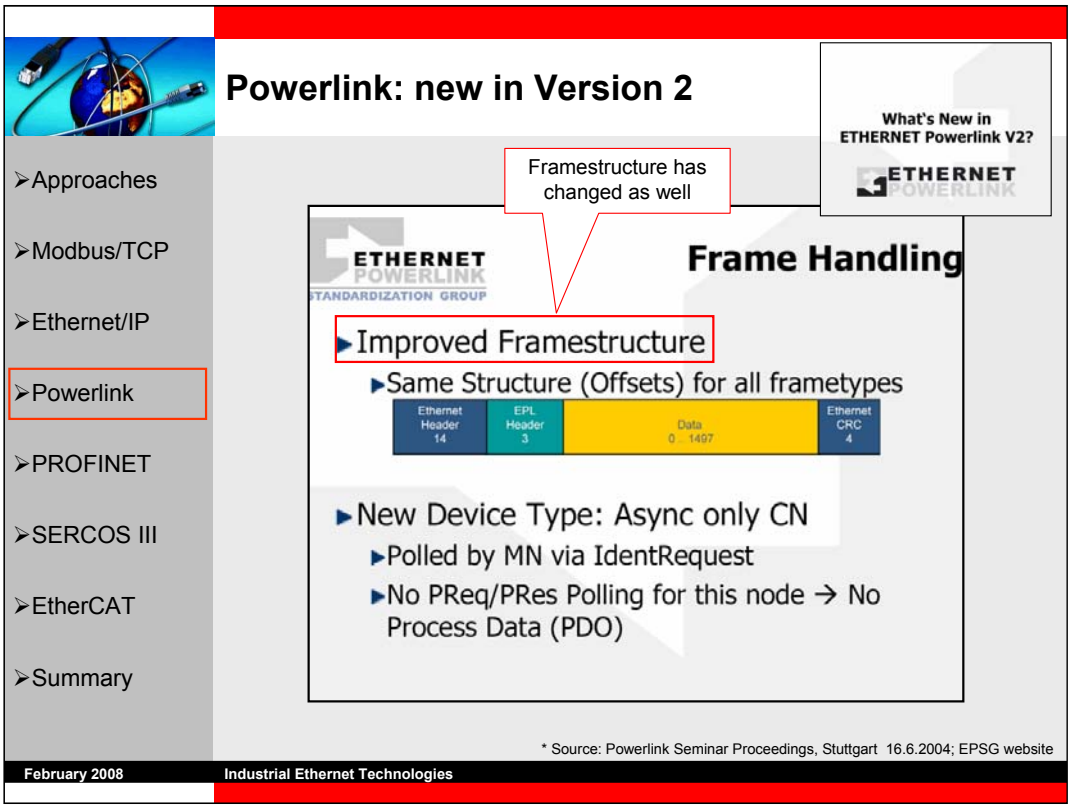
It is important to distinguish between Powerlink Version 1 and Version 2, since both versions have little in common: both use half duplex hub technology and Polling over Ethernet. (similar to CANopen and DeviceNet: both use CAN).



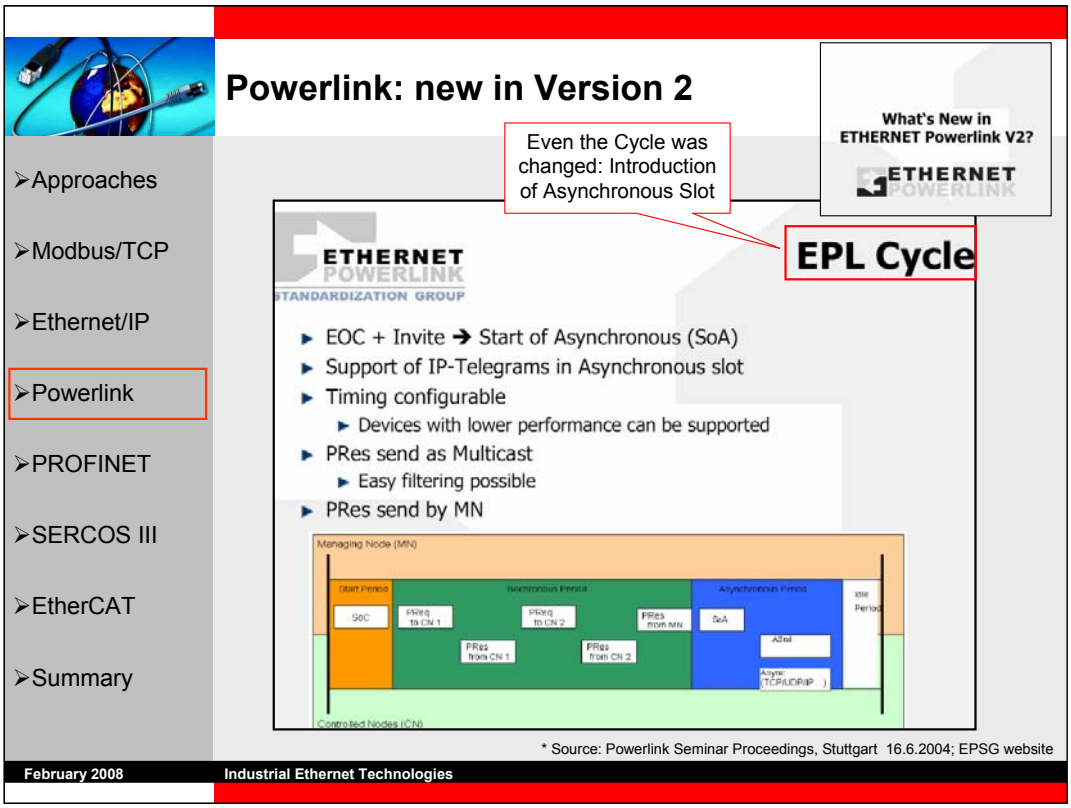
In Powerlink Version 1 all nodes used the same MAC address, which violates IEEE 802.3. Thus the MAC layer of Version 1 is incompatible with Version 2.

Protocol addressing (EPL + IP) has changed as well.

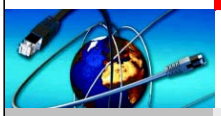
The Powerlink Spec (V2) demands that IP-capable nodes have a fixed private IP address. This means that even in a future open mode routers with NAT have to be used to access Powerlink nodes via IP protocols.



The frame structure was changed from V1 to V2 – and is thus incompatible.



The cyclic behavior of the network was changed as well.



Gigabit Powerlink – 10 x faster?

ETHERNET POWERLINK

- Approaches
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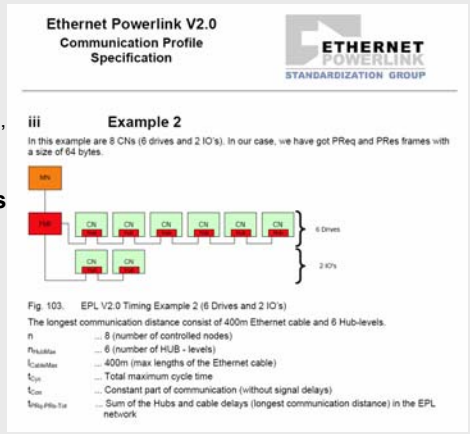
- SERCOS III
- EtherCAT
- Summary

Performance Example 2 from Powerlink Specification V2,
Process Data Communication only,
no bandwidth for acyclic communication,
Hubs, no Switches:

Cycle Time with 100 MBit/s: **323 µs**
Cycle Time with 1 Gbit/s: **245 µs**

Performance Gain: Factor **1,38**

For Example:
EtherCAT Cycle Time
(@ 52% Bus load): **28 µs**


Ethernet Powerlink V2.0
Communication Profile Specification

ETHERNET POWERLINK STANDARDIZATION GROUP

iii Example 2

In this example are 8 CNs (6 drives and 2 IO's). In our case, we have got PReq and PRes frames with a size of 64 bytes.

Fig. 103. EPL V2.0 Timing Example 2 (6 Drives and 2 IO's)

The longest communication distance consist of 400m Ethernet cable and 6 Hub-levels.

n ... 8 (number of controlled nodes)
... 6 (number of HUB - levels)
... 400m (max lengths of the Ethernet cable)
... Total maximum cycle time
... Constant part of communication (without signal delays)
... Sum of the Hubs and cable delays (longest communication distance) in the EPL network

February 2008 Industrial Ethernet Technologies

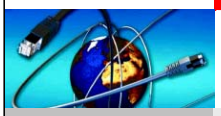
In November 2006, EPSG announced Gbit Powerlink, claiming the network performance would be 10 times. (Quote from Powerlink "Facts" 1/2007: "*POWERLINK users can easily boost network performance by a factor of 10. Changing the hardware platform to include 1 Gigabit hardware instead of 100 Mbit components is all any developer must do, resulting only in a somewhat different list of components to be fitted onto an otherwise identical PCB*.")

Doing the maths shows that the performance gain would be minimal. Depending on the configuration, a factor of 1.38…2 can be expected, if the same frame length is not changed from 100 MBit/s (IEEE802.3 specifies 512 Byte minimum frame payload for GBit hub based systems).

There are indications, however, that it is intended to use switches in conjunction with Gbit Powerlink. In this case the additional delay introduced by switches instead of hubs will undo the performance gain of the higher transmission rate: so it can be expected, that Gbit Powerlink will be **slower** than 100MBit Powerlink.

In addition, announcing GBit Powerlink further confuses the potential implementers: should he implement V1, V2, or wait for Gbit?

Furthermore, chips in Gbit mode draw much more power which would be a problem for many automation devices.



Gigabit Powerlink – 10 x faster?

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
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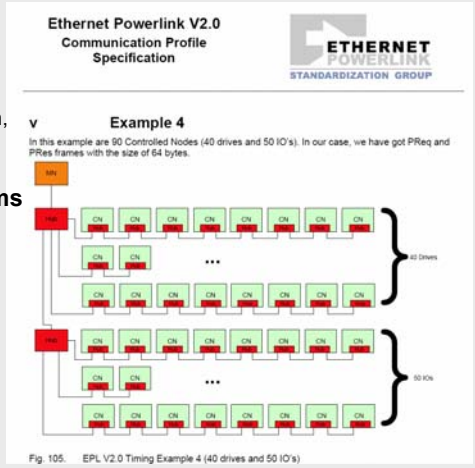
- SERCOS III
- EtherCAT
- Summary

Performance Example 4 from Powerlink Specification V2,
Process Data Communication only,
no bandwidth for acyclic communication,
Hubs, no Switches:

Cycle Time with 100 MBit/s: **2,39 ms**
Cycle Time with 1 Gbit/s: **1,45 ms**

Performance Gain: Factor **1,64**

For Example:
EtherCAT Cycle Time
(@ 44% Bus load): **0,28 ms**


Ethernet Powerlink V2.0
Communication Profile Specification
ETHERNET POWERLINK
STANDARDIZATION GROUP
v
Example 4
In this example are 90 Controlled Nodes (40 drives and 50 IO's). In our case, we have got PReq and PRes frames with the size of 64 bytes.
MN
CN
40 Drives
50 IOs
Fig. 105. EPL V2.0 Timing Example 4 (40 drives and 50 IO's)

February 2008 Industrial Ethernet Technologies

In November 2006, EPSG announced Gbit Powerlink, claiming the network performance would be 10 times. (Quote from Powerlink “Facts” 1/2007: “*POWERLINK users can easily boost network performance by a factor of 10. Changing the hardware platform to include 1 Gigabit hardware instead of 100 Mbit components is all any developer must do, resulting only in a somewhat different list of components to be fitted onto an otherwise identical PCB*.”)

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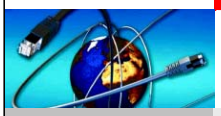

Gigabit Powerlink – 10 x faster?

ETHERNET POWERLINK

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- SERCOS III
- EtherCAT
- Summary

- Powerlink Performance Gain by changing from 100 Mbit/s to 1 Gbit/s ca. Factor 2
- Probably no Gain at all if Switches are used for Gbit
- Effort:
  - 8 instead of 4 Wires (Field Mounting?)
  - no M12
  - Power consumption significantly higher (PHY + MAC)
- Ergo: Powerlink has a Performance Issue, which is not solved by announcing Gbit Powerlink
- 100Mbit already outdated, Gbit not yet available: if you were Device Vendor, would you implement Powerlink now?

In November 2006, EPSG announced Gbit Powerlink, claiming the network performance would be 10 times. (Quote from Powerlink “Facts” 1/2007: “*POWERLINK users can easily boost network performance by a factor of 10. Changing the hardware platform to include 1 Gigabit hardware instead of 100 Mbit components is all any developer must do, resulting only in a somewhat different list of components to be fitted onto an otherwise identical PCB*.”)

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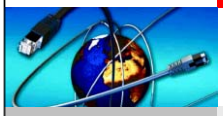
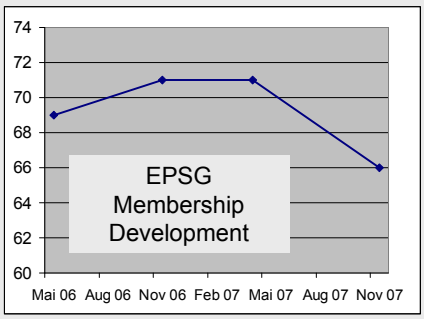


Ethernet Powerlink Standardization Group

- ➢Approaches
- ➢Modbus/TCP
- ➢Ethernet/IP
- ➢Powerlink
- ➢PROFINET
- ➢SERCOS III
- ➢EtherCAT
- ➢Summary

- EPSG originally hosted by Institute of Embedded Systems, Zurich University Winterthur (Switzerland)
- In 2006, EPSG Office moved to marketing agency in Aachen, Germany
- In 2007, EPSG Office moved to advertising agency in Berlin, Germany
- 2007: New Logo and CI
- Recent Membership Development: from 69 members in 5/2006 to 71 members in 11/2006 to 71 members in 4/2007 to 65 members in 11/2007*



* Source: Powerlink Facts May/Nov 2006/April/Nov 2007, published by EPSG; EPSG website

Ethernet Powerlink Standardization Group is managed and hosted by an advertising agency. Technical and implementation support is available by technology providers (only), who charge for these services.

ETG acknowledges that membership figures of EPSG and ETG cannot be compared directly: EPSG charges between 500€ and 5000€ per annum for membership, whilst ETG has adopted the philosophy that charging for access to a technology is not a sign of openness.

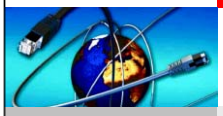
Therefore in brackets: (Between 5/2006 and 11/2007, ETG grew from 315 to 634 members, reaching 670 members on January 15, 2008).

The figures discussed above were taken from the EPSG publication “Powerlink Facts”, which is available for download from the EPSG website. There all members are listed.

According to EPSG news, one company (Yacoub Automation) joined EPSG at SPS/IPC/Drives in Nov 2007.

Please note that EPSG typically uses the term “members, supporters and users” when referring to membership levels, and accumulates those to over 400* (as of 5/2007).

* The EPSG website e.g. lists Tetra Pak in the members and users list. According to a Tetra Pak R&D manager, they used Powerlink in one R&D project which was later cancelled, never delivered a Powerlink equipped system and also terminated their EPSG membership.



Powerlink Summary

ETHERNET POWERLINK

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Polling over Ethernet
- All Frames are broadcasted
- Cycle times similar to SERCOS-II
- Performance difficult to predict: depends on selected devices and on topology.
- Requires protected network segment
- Requires substantial processing power (master + slave) or implementation in hardware (e.g. FPGA)

- Based on (outdated) half duplex Hub technology
- Limited no. of nodes can be connected in line topology
- requires Master with dedicated Communication processor: no Commercially of the Shelf (COTS) Network interface card (NIC)
- Version 2 is not field proven yet
- Version 2 is not downwards compatible.

Due to the polling principle, the master has to wait for the response of each slave before he can send the next request – or has to wait for the timeout.

The response time of each slave device depends

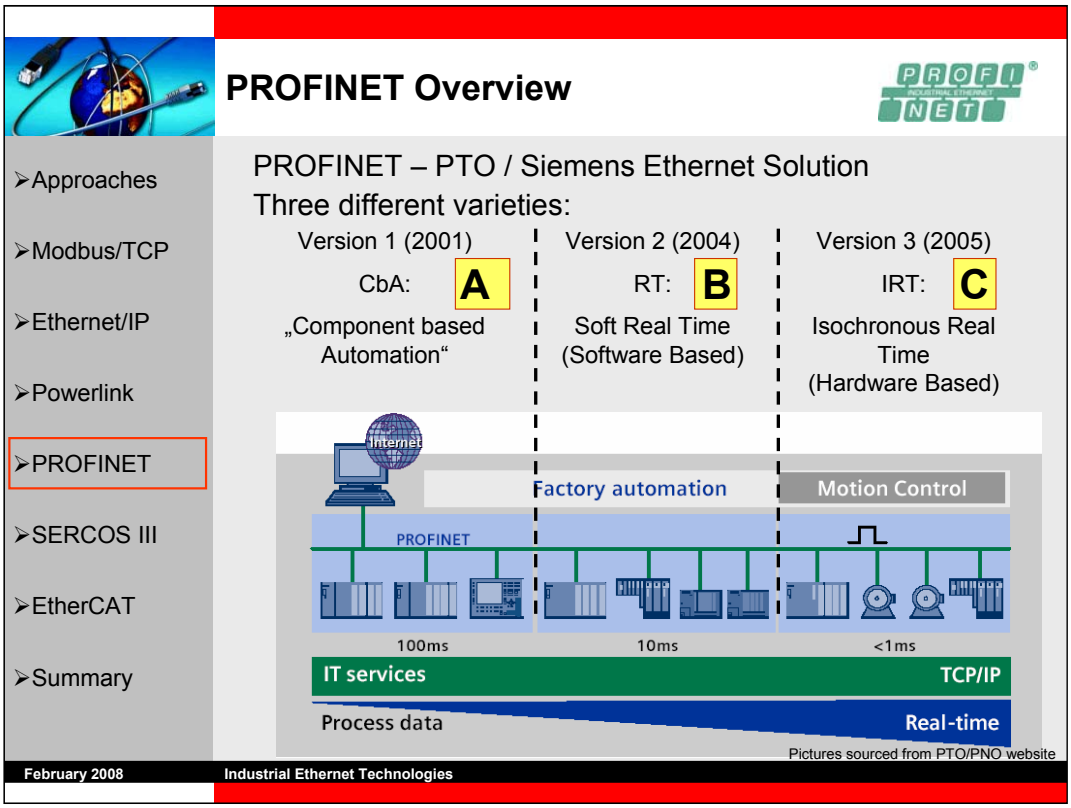
• on its individual implementation:

- if implemented with standard components: processor performance, software stack implementation quality, varying local CPU load due to application etc.
- or: implemented with FPGAs

• and on the topology (number and performance of the hubs in between).

Thus it is difficult to determine the performance of the network without measuring it.

Performance limitations require complex bandwidth optimization in more demanding applications.



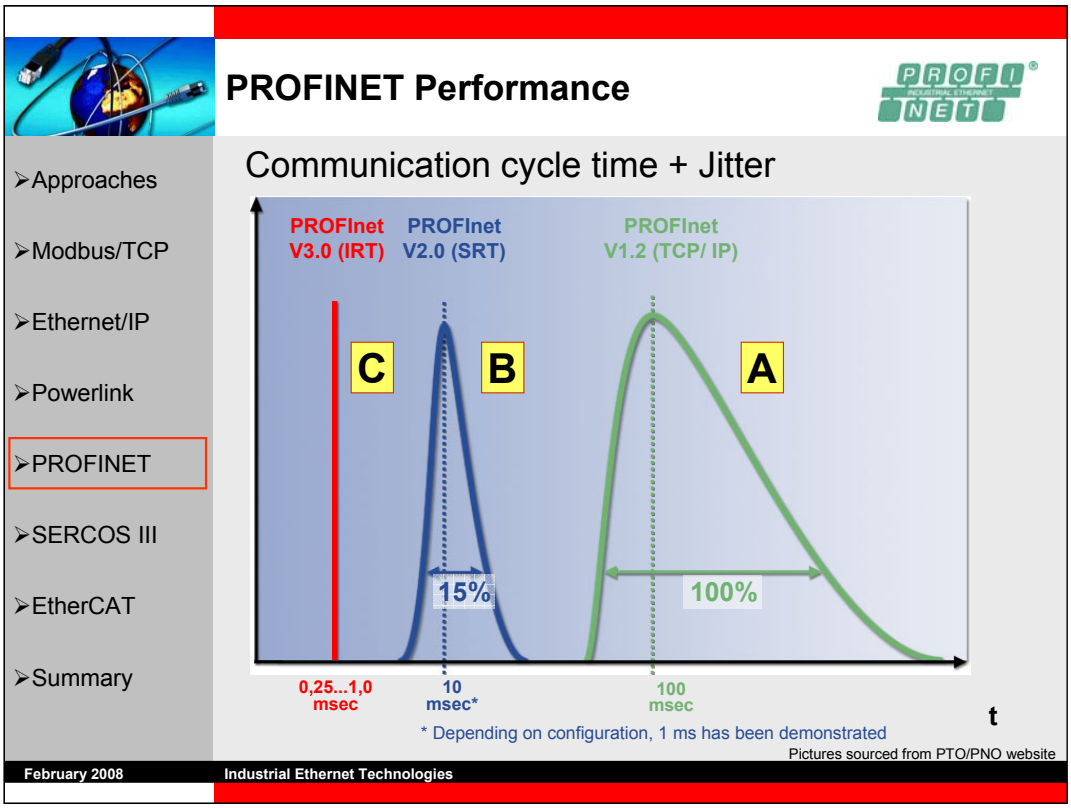
There are 3 PROFINET-Versions:

Version 1 („Component Based Automation“), a Class A approach

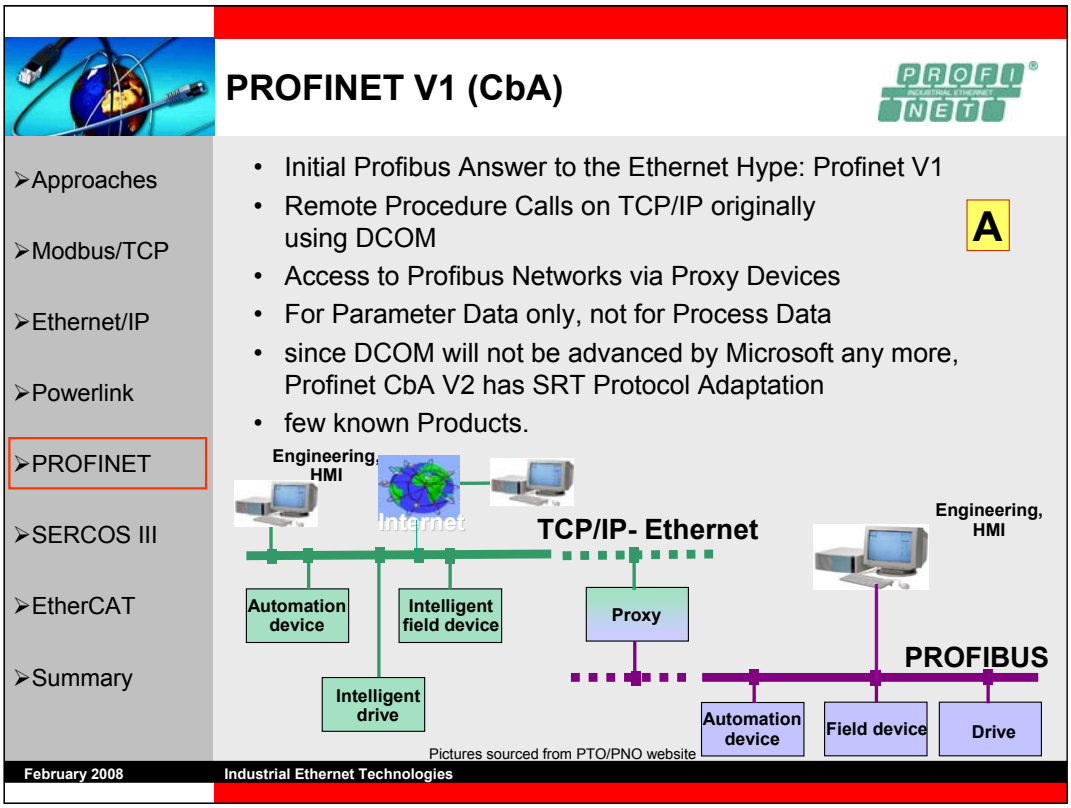
Version 2 ((Soft) Real Time“), a Class B approach

Version 3: („Isochronous Real Time“), a Class C approach

PNO tries to move away from the terms RT/IRT and introduce the term Profinet IO for both approaches..

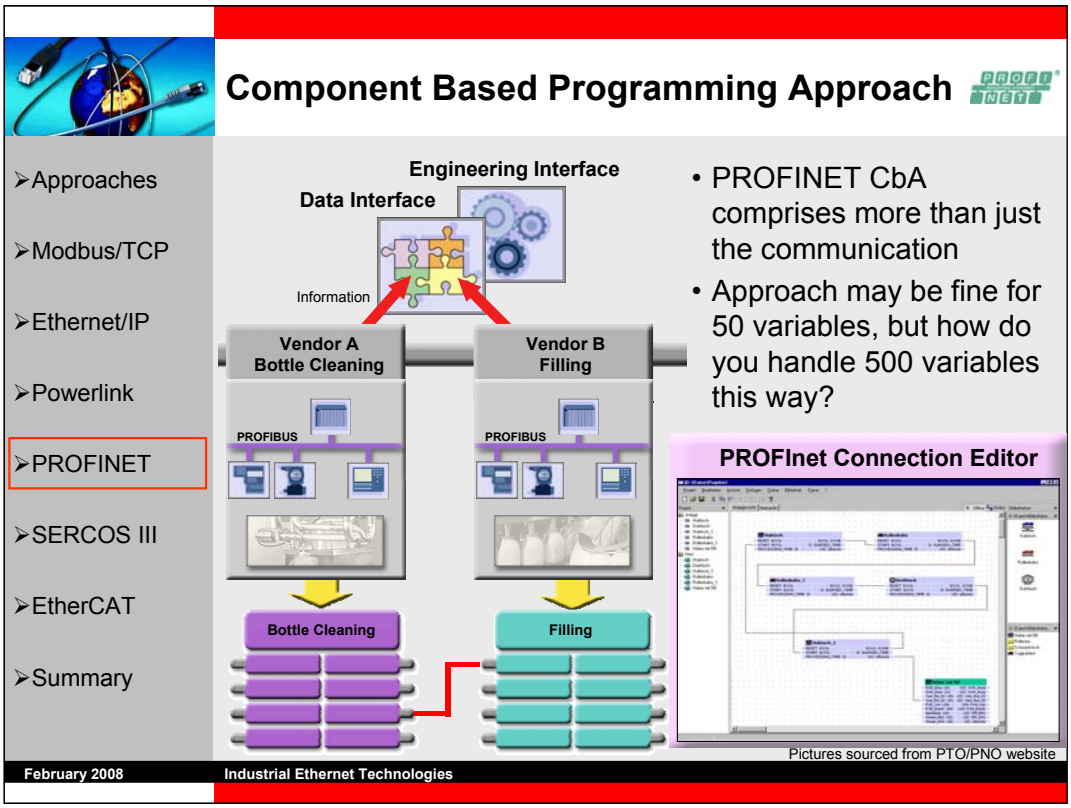


The cycle time range 0.25…1ms for IRT is misleading. Initially, most (if not all) IRT devices will **not** support cycle times < 1 ms.



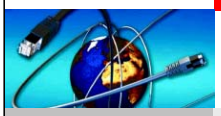
Initially the PNO/PTO message was: protect your investment and continue using Profibus, for Ethernet connectivity we provide a transparent gateway.

Work on the gateway (proxy) concept was started as early as 1999. First spec (V0.9) published in March 2001 (Ethernet/IP was first introduced in 2000).



- PROFINET CbA comprises more than just the communication
- Approach may be fine for 50 variables, but how do you handle 500 variables this way?

Profinet CbA (Component Based Automation) comprises more than just a communication protocol: the CbA programming approach with graphical mapping of variables to establish communication links.



PROFINET V2 (RT)

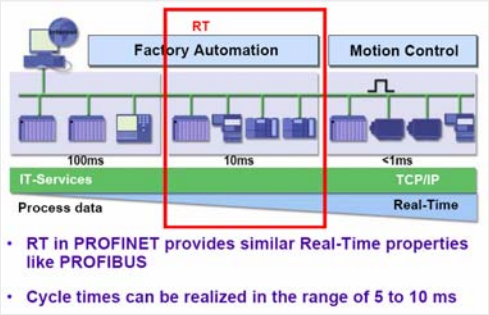
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

B

- First named „Soft Realtime“ (SRT)
- „Best Effort“ Protocol with 5 .. 10 ms typical cycle time and 15% jitter
- Modified Stack bypasses TCP and IP for Realtime-(process)data
- Aimed at and suited for PLC type applications (including drive control, but not motion control)
- Requires substantial amount of software (Field device: ~ 1MByte)

Limitations:

- Soft Realtime Solution with
  - Influence by TCP traffic
  - Inpredictable Queue delays in switches
  - Stack delays
- Standard Controllers are sensitive for IP Multicast Traffic



- RT in PROFINET provides similar Real-Time properties like PROFIBUS
- Cycle times can be realized in the range of 5 to 10 ms

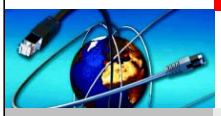
Pictures sourced from PTO/PNO website

Profinet V2 was initially called SRT (Soft Real-time). The term „soft“ was later dropped for marketing reasons.

Profinet RT is also addressed as Profinet I/O (together with IRT).

Siemens has started to communicate that Profinet RT will provide similar performance as Profibus. Even though this is optimistic (typically Profibus should be faster), one can read this statement as follows:

If Profibus performance is sufficient, but Profibus is not expensive enough, Profinet RT is an alternative ;-)



PROFINET V2 (RT) and V3 (IRT)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

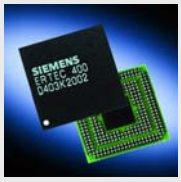
V2 Real-Time (RT)

- Software Solution with Standard Controller
- Usage of Standard Network Components
- Real-Time as good as provided by
  - Switching Technology
  - VLAN-Tagging (Prioritization, IEEE802.1q)

B

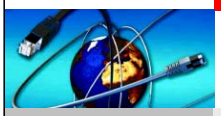
V3 Isochronous Real-Time (IRT)

- Synchronization of all nodes
- Bandwidth reservation for isochronous Data
- Requires Special Hardware ASIC



C

Profinet IRT is a class C approach which introduces special hardware in order to achieve sufficient performance and synchronicity for motion control applications.

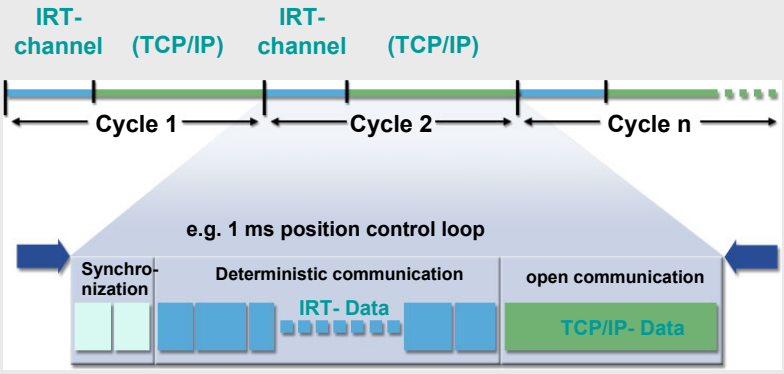


PROFINET V3 (IRT) Features

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Timeslicing Approach by special Switch ASICs
- Switches can be integrated into devices
- Topologies: Line (up to 25 nodes), Branch, Tree supported
- Cycle Time 250 µs to 4 ms, 1 µs jitter

C



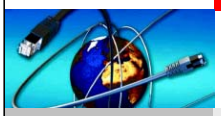
Pictures sourced from PTO/PNO website

Profinet IRT is a class C approach which introduces special hardware in order to achieve sufficient performance and synchronicity for motion control applications.

The minimum cycle time is determined by the approach to include generic TCP/IP traffic in a gap wide enough for the largest Ethernet frame.

This approach leads to limited bandwidth utilization, since even though most applications only have sporadic TCP/IP communication, the bandwidth remains reserved for this kind of traffic.

Even though the specification allows for cycle times starting from 250µs, all but one Siemens IRT master devices only support cycle times starting from 0.5 ms.

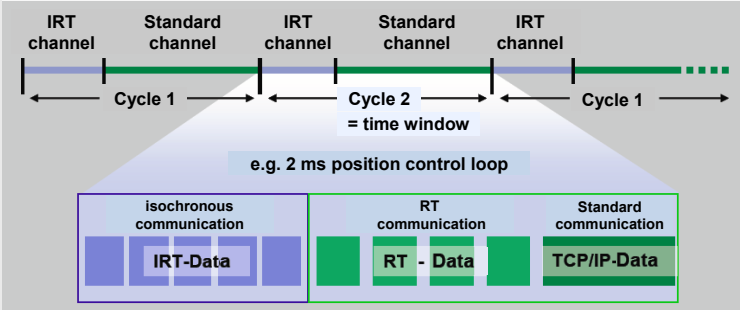


PROFINET V2 (RT) and V3 (IRT)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

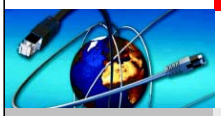
Both versions can be mixed, if

- supported by master
- only IRT switches are used
- enough bandwidth available



In principle both varieties (RT+IRT) can be mixed. Since IRT switches have to be used then, one can say:

RT devices can be integrated in IRT networks, if there is sufficient bandwidth and if the master supports this.



PROFINET IRT System Planning (I)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

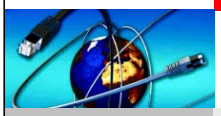
Input for planning/configuration of the network:

- the topology of the network
- and for every transmission
  - the source- and the target node,
  - the amount of transmission data,
  - projected features of the connection path (e.g. Redundancy)

Output of the projection for every transmission and switch:

- Ports and exact transfer time timing for each frame

Besides hardware costs, the crucial issue of Profinet IRT is the complex system planning.



PROFINET IRT System Planning (II)

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Complex recursive optimization problem
- Configuration and System Planning is a process executed by a central Algorithm in the Engineering System.
- Small change in input (e.g. one more node) may lead to big change in output (cycle time and thus performance), due to unpredictable behavior of optimization algorithm

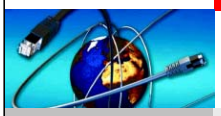
⇒ Strong interdependency between topology and performance

And: **This Algorithm is SIEMENS IP and not** (yet?) **open.**

For each node all communication relationships have to be known and scheduled. Of course there are strong interdependencies between the schedules. Therefore the system planning is a complex recursive optimization problem without a straightforward solution – even with fairly simple topologies.

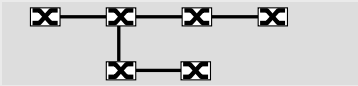
Due to the complex nature of this problem the optimization algorithm may come up and be satisfied with a relative rather than the absolute optimum – which means, that a small change in the configuration (e.g. adding just one more node) may result in large changes in the network performance.

To our best knowledge the planning algorithm is not open.



IRT Topology – and some conclusions

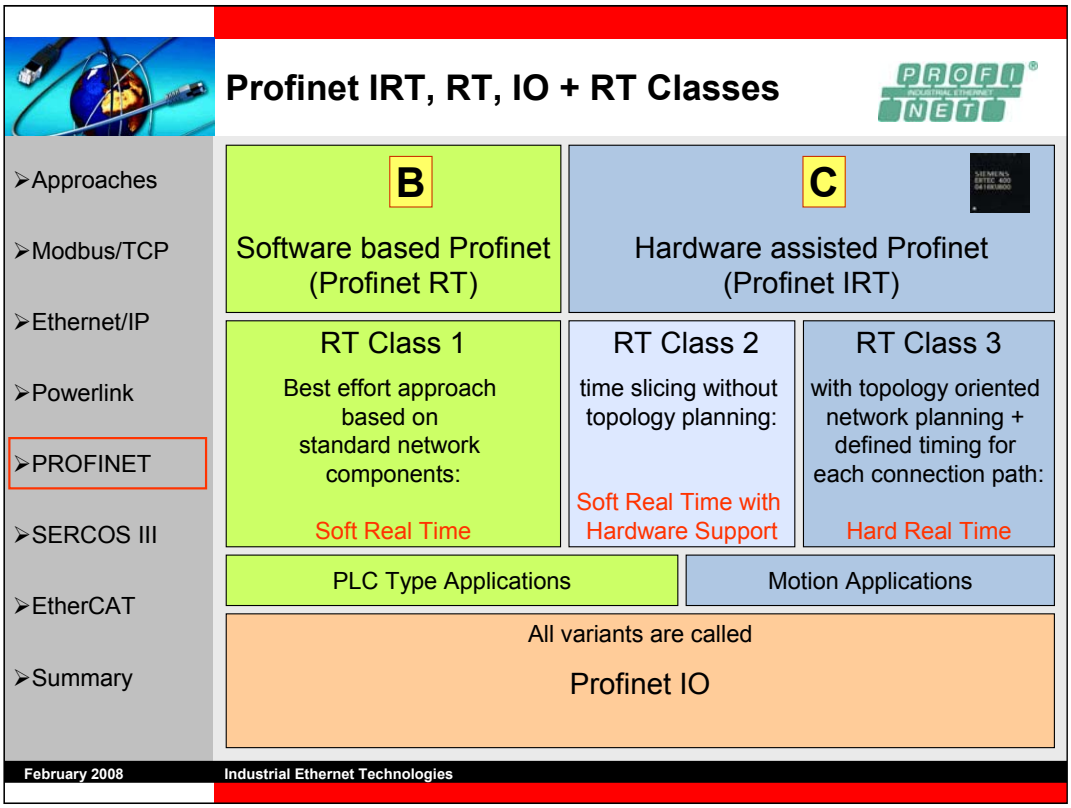
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary



- Line, Branch, Tree Topology is supported
- Cascading of switches in a line has limit of 20 - 25 devices
- → this means: branch/star topology is the common design, whether desired or not
- For any installation with more than 20 - 25 devices, network branches are required
- The network topology layout requires a top-down approach
- The planning process will mandate the layout and wiring of a configuration
- performance data is true for a specific topology ONLY
- Topology restrictions apply when designing a network with a required performance

Pictures sourced from PTO/PNO website

The strong – but non-linear and even unpredictable – interdependency between topology and performance may require several iterations (or „try and error“ steps) when designing a network layout for a required performance.

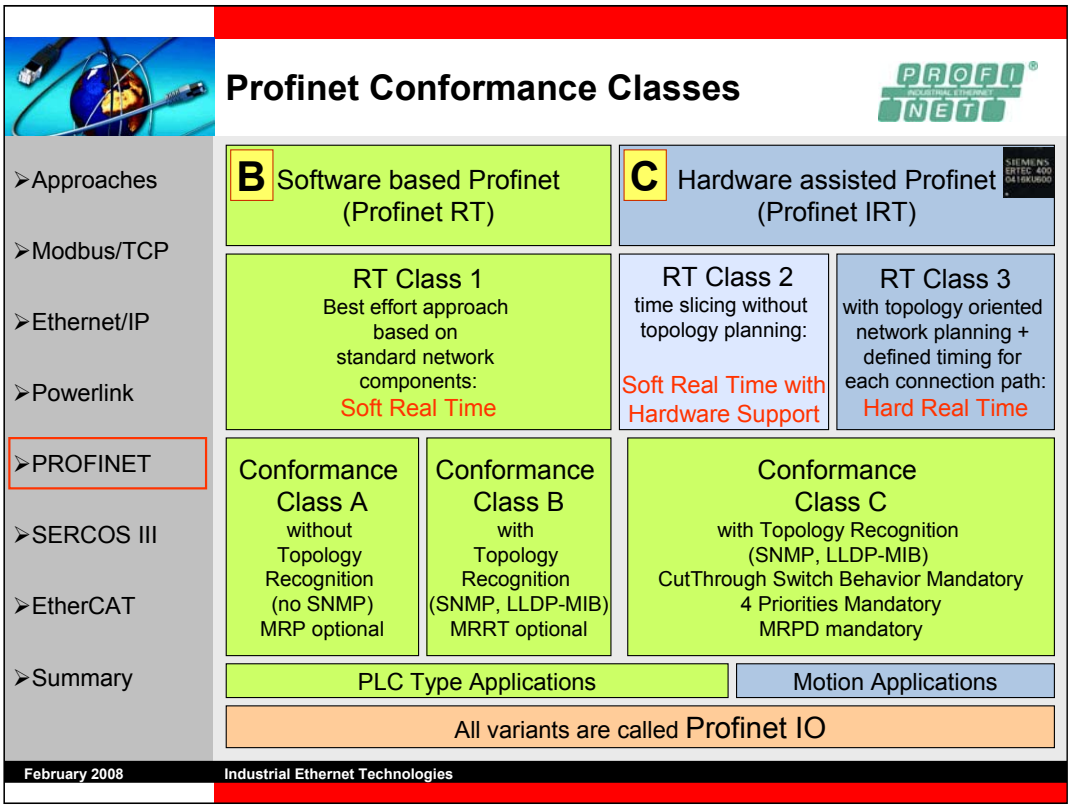


In order to avoid the complex topology network planing process, an intermediate approach has been introduced: RT Class 2 (within Siemens also called IRT “Flex”) using Profinet chips (e.g. ERTEC). High priority network traffic is sent in the IRT time slice, but without predefined timing for each connection. Low priority communication is handled in the NRT time slice.

This improves the network performance in case of mixed communication (if the application has NRT traffic such as TCP/IP), but does not guarantee synchronous real time behavior under all circumstances. Profinet chips have to be used throughout. Cyclic behavior can be achieved if the network load is low and the application tasks are synchronized with the communication cycle. Main application field for RT class 2 are PLC type applications, but network performance should also be sufficient for small motion control applications.

RT Class 3 (also called IRT “TOP”) is the variant formerly referred to as Profinet IRT. This approach provides hard real time behavior but requires the detailed network planning and the optimization algorithm.

PTO/PNO generally downplays the differences between the Profinet variants, summarizing all of them with the term “Profinet IO”.



In addition to the RT classes, Profinet has introduced (see IEC 61784-2) **Application Classes** (Isochronous for motion control, Non-isochronous for factory process + building automation),

Redundancy Classes (MRP: Media redundancy protocol; MRRT: Media redundancy for real-time; MRPD: media redundancy for planned duplication) and

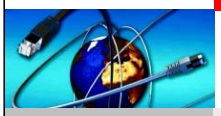
Conformance Classes. The Conformance Classes predominantly define the support for the topology recognition features. Redundancy Classes and Conformance Classes are interlinked.

Topology Recognition is supported in Conformance Class B + C, only.

It was found that there are issues when using unmanaged switches with Profinet Class A (in B managed switches are mandatory): common COTS switch chips forward LLDP (Link Layer Discovery Protocol) frames to all ports, which leads to substantial additional network traffic (the frames are handled like broadcast frames).

Conclusion: **even though in principle unmanaged switches can be used with Conformance Class A Profinet networks, they have to be selected very carefully (IT support required).**

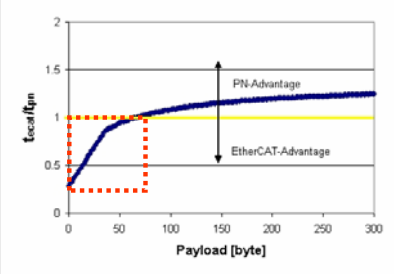
see also EFTA 2007 Conference Paper by Iwan Schafer + Max Felser, Berne University of Applied Sciences: “Topology Discovery in PROFINET”: http://www.felser.ch/download/ETFA-01-2007.pdf



Next Generation Profinet IRT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- On press conferences in Nov 2007, PNO/PTO published performance comparsions with EtherCAT
- It was found that in typical application scenarios (line structure, 50 nodes, < 60Bytes cyclic data per node) EtherCAT is substantially faster than Profinet IRT
- According to the PNO, Profinet IRT is faster if the average payload per node exceeds 60 Bytes
- However, some features of EtherCAT (such as full-duplex frame usage and pipelining of frames) were not considered



Picture sourced from PNO press kit

February 2008 Industrial Ethernet Technologies

Within the research project “ESANA”, funded by the German Federal Ministry of Education and Research, Siemens, Phoenix Contact and some other parties are looking for performance enhancement possibilities for Profinet. This is remarkable, since it documents that in PNO/Siemens/Phoenix view Profinet IRT is not fast enough to succeed.

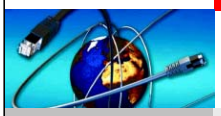
The performance comparison shown on this slide is at least questionable: even with very favorable assumptions for Profinet it was not possible to reproduce the results. EtherCAT is substantially faster than shown, since several EtherCAT features were not taken into account:
- EtherCAT can use the same bandwidth for input and output data (full-duplex usage of the frame).

- EtherCAT can send the next frame before the first one has returned (pipelining of frames).

One of the authors of the study has meanwhile admitted this shortfall.

So in fact EtherCAT is faster than Profinet IRT, regardless of the payload per node.

Furthermore, all the Profinet calculations do not include the local stack performance in the slave devices. Unlike with EtherCAT, in a Profinet IRT slave device a communication µC (ERTEC: ARM) is taking the data from the MAC interface and makes it available to the application. With EtherCAT, this is done on the fly in hardware, the data is made available in the DPRAM or Input/Output of the EtherCAT Slave Controller without further delay.



Next Generation Profinet IRT

- Approaches
- Modbus/TCP
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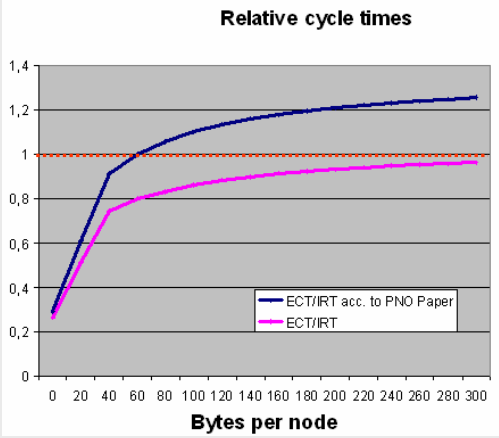
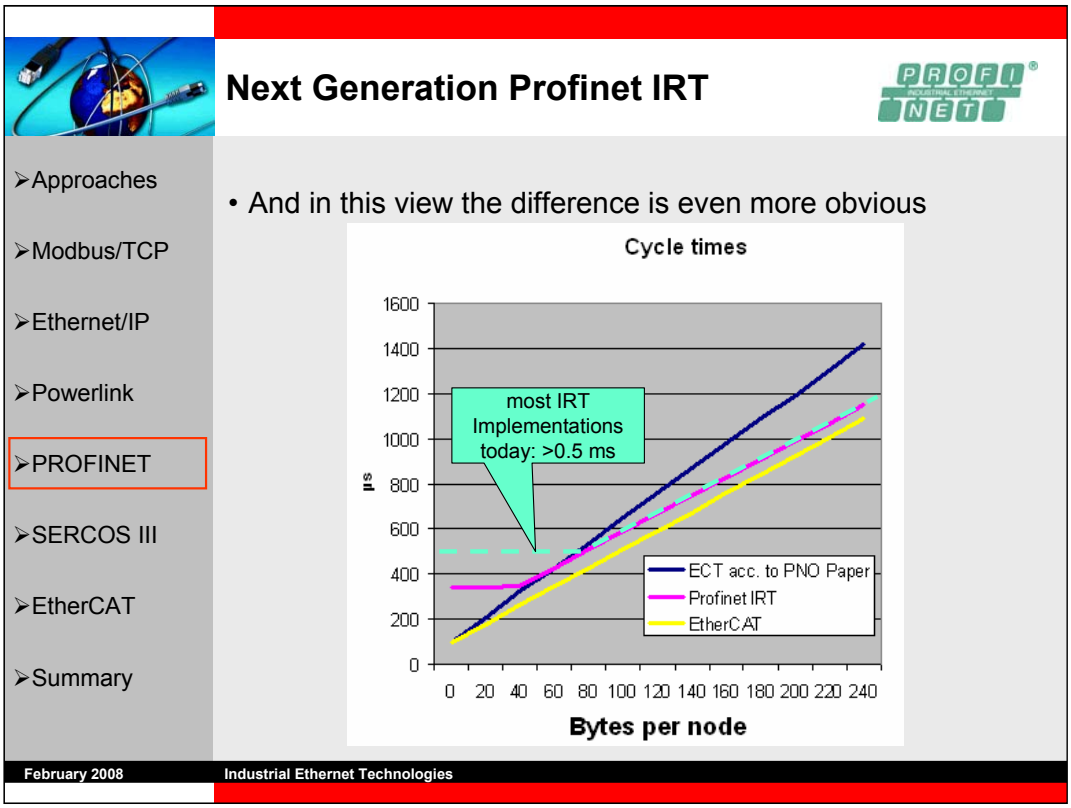
- PROFINET
- SERCOS III
- EtherCAT
- Summary

• When taking all EtherCAT Features into account, the performance comparison looks different:



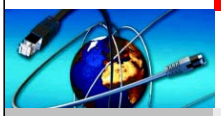
This slide shows the relative performance comparison if all the EtherCAT Features are taken into account (purple line). The blue line shows the comparison according to the PNO paper.



And here the absolute cycle times are shown.

According to the Siemens product manuals, all but one current Profinet IRT master implementations start at 0.5 cycle time, so that shorter cycle times are of more theoretical nature.

Please note that one major EtherCAT feature is still not included in the comparison: the ability to combine short and longer cycle times. So e.g. drives can be updated faster than shown if the update rate of other devices such as analogue inputs is decreased.



Next Generation Profinet IRT

- Approaches
- Modbus/TCP
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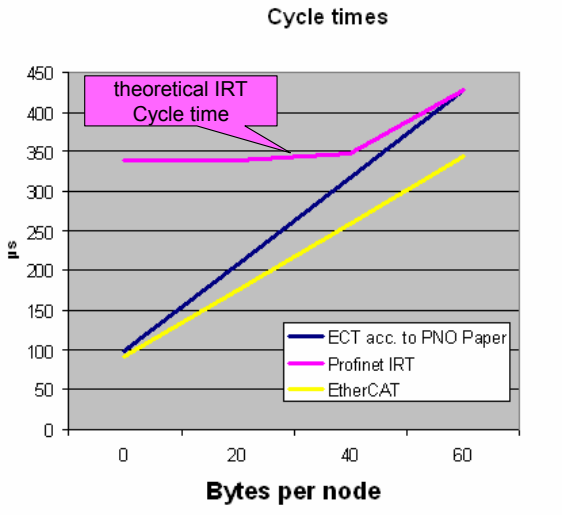
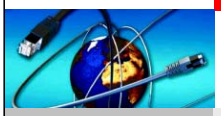
- SERCOS III
- EtherCAT
- Summary

• In particular if one looks at the most relevant area < 60 Bytes



And this cycle time comparison looks at the most relevant are of up to 60 bytes average process data size per node.

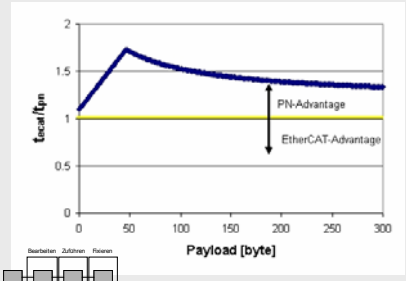
We have not seen a control system yet in which the average process data size per node exceeded this value.

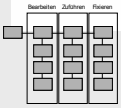


Next Generation Profinet IRT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- PNO also showed a special application scenario (comb structure with 8 branches in which the nodes in the branch lines are only updated every 8th cycle), in which Profinet IRT will allegedly exceed EtherCATs Performance
- Also a new Profinet IRT Version (Profinet V4?) which requires new ASICs was announced
- The new ASICs are expected in 2009
- In October 07 the price for the old ASICs was reduced by 40%





- Main Line with k=8 nodes in each bus Cycle
- Drop lines with n=10 nodes in each 8th Cycle
- Distance between nodes 50m

Picture sourced from PNO press kit

PNO intends to show a Profinet V4 demonstrator in April 2008 at Hannover Fair. ASICs supporting this version will be available in 2009. According to Siemens statements the new ASICs will not support Gigabit.

ETG was asked to provide a statement regarding the PNO press conference. Here it is:

•We are pleased that the PNO has chosen EtherCAT as performance benchmark and thank for the associated publicity.

•The PNO acknowledges our statement, that high-end performance with cycle times significantly below 1 ms is a relevant selection criteria for an Industrial Ethernet solution.

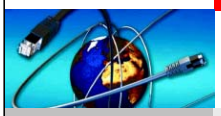
•The PNO analysis shows clearly, that in typical application scenarios EtherCAT is much faster than the fastest Profinet variant IRT class 3.

•We congratulate the PNO on having found a special scenario (comb structure, in which the nodes in the branch lines are not updated in each cycle), in which a future version of Profinet IRT seemingly matches or exceeds EtherCATs performance.

•This comb structure was compared with an EtherCAT line structure – and not with an EtherCAT comb structure, in which the nodes in the branch lines can be updated in each cycle.

•EtherCAT is and remains the fastest Industrial Ethernet solution.

•EtherCAT does not need and will not need the complex network planing and optimization that current and future Profinet IRT variants require.



PROFINET ASIC Pricing

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

	ERTEC 200	ERTEC 400
Functionality	**PROFInet RT + IRT** **IEEE 1588** **ARM 9 Processor** 2 Port Switch with PHY	**PROFInet RT + IRT** **IEEE 1588** **ARM 9 Processor** 4 Port Switch, no PHY PCI Interface RMII Interface (4port)
Application field	Single drives **Comparable field devices**	High-end Motion Controller **Network components**
ASIC Technology	**0.15 µm Technology** **304pin BGA 19 x 19 mm**	**0.15 µm Technology** **304pin BGA 19 x 19 mm**
Pricing	12.57 € @ order size 350 units	30.00 € @ order size 350 units

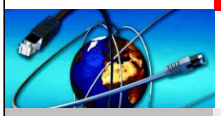
Pricing shows that PROFInet is more on the „complex“ field device network side than on the cost efficient I/O system side.

First samples of the ERTEC 400 were shipped in May 2005, first samples of the ERTEC 200 were shipped in May 2006.

Initially, the ERTEC 400 was sold for 38€ and the ERTEC 200 for 19 € per chip (@ 10.000 units/year). As of Oct 1st, 2007, Siemens lowered the prices substantially, presumably since the next generation IRT which requires new ASICs is under development.

12.57€ respective 30€ per chip still exceeds fieldbus cost levels not only for simple devices, in particular if one considered the amount of memory needed:

A Profinet slave device needs about 1 MByte of Code for the communication part. For implementation with ERTEC chips, a VxWorks license is required: the stack is provided as object code for this RTOS.



PROFINET and INTERBUS

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

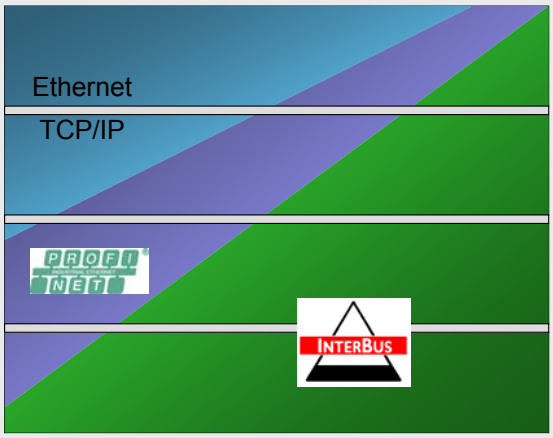
the Interbus View…

Management Level

Control Level

Complex field devices

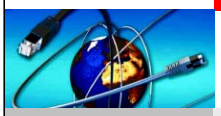
Simple field devices



…there is life below PROFINET…

Picture sourced from Interbus Club website

Due to system complexity and costs Interbus as well as Profibus expect life below Profinet.



PROFINET Summary

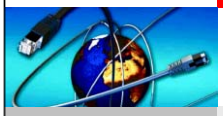
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- 3 different Versions:
  Proxy Approach, Soft Real Time, Isochronous Real Time
- Proxy Approach: vaporware
- RT: rather complex Profibus replacement, but will have market share due to support by Siemens
- There will be underlying networks (for cost reasons)
- IRT for motion control: meets motion control requirements but very complex and expensive
- IRT expected to be predominantly Siemens only
  (like Profibus DPV2 for Motion Control)

Profinet RT is not low cost, requires a lot of code and is not high performance, but it will be a success – regardless of the technology, simply due to the Siemens (+ PNO/PTO) market position, just like Profibus.

The German car makers have announced to use Profinet RT in car assembly lines „if it provides technological and economical advantages“ (quote). Daimler, e.g., has clearly stated that this announcement does not cover the power train business, where CNC and other motion control applications are in place. Furthermore, there will be underlying fieldbus systems in the car assembly line, too. But certainly the auto makers announcement gave Profinet RT a marketing push.

The situation is different for Profinet IRT: A solution with sufficient performance, but with rather expensive chips and a very complex network planning and configuration tool where the key algorithms are not open. IRT is aimed at servo motion control applications and will – just like Profibus MC – be a Siemens motion control solution with limited support from third party vendors (just like Profinet MC). Plus, Siemens latest Motion Control product line prefers a different communication link for closed loop control: DriveCliq, which uses Ethernet physical layer, only.



SERCOS III Features

SERCOS interface

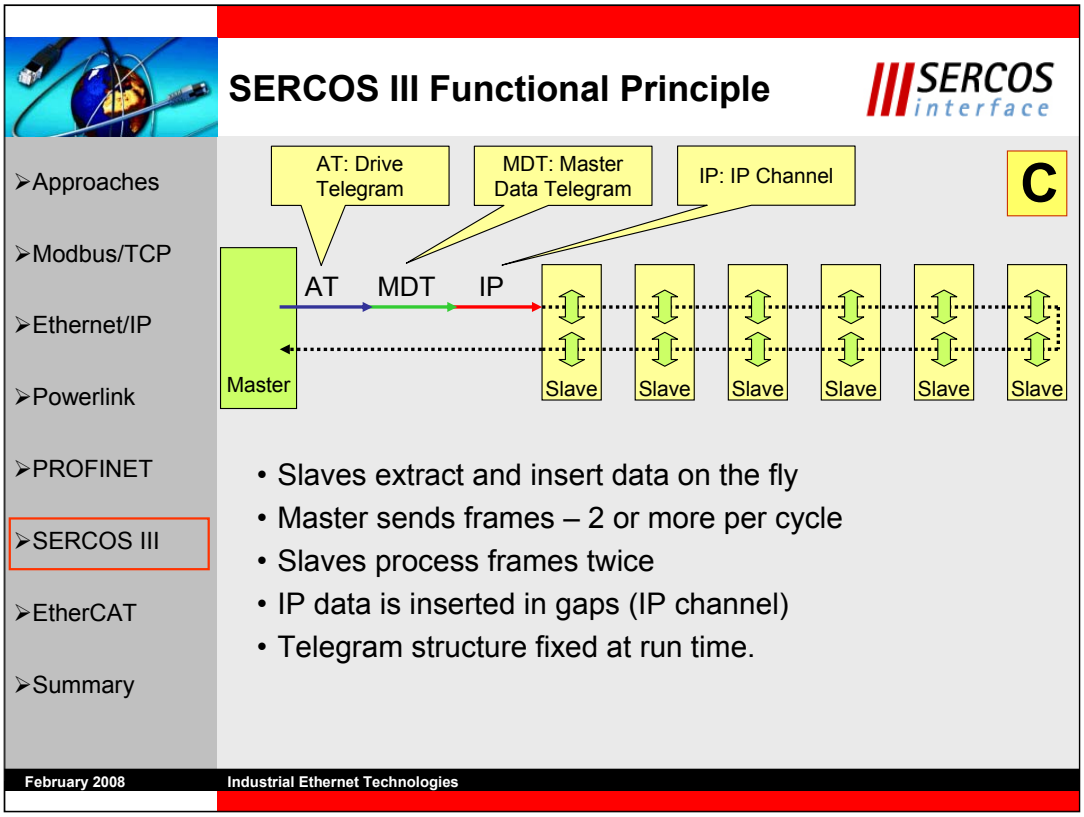
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

C

- Combining Sercos mechanism with EtherNet Physics
- 100 MBit network transmission rate
- Hardware based synchronization and ring topology
- Integration of TCP/IP channel
- Cyclic and acyclic communication
- Cross-communication between slaves
- Media redundancy support
- Control recognizes the physical order of devices
- 100BASE-TX or POF based physical layer

- Requires Special Master Card
- maximum of 254 slave nodes per network
- Line + Ring Topology, only.

The list of features of SERCOS-III reads like the list of features of EtherCAT – except the last three items.

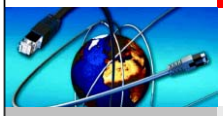


SERCOS-III has adopted the EtherCAT functional principle: processing Ethernet frames on the fly. There are some main differences, though:

1. SERCOS-III separates input and output data in two frames – so there are at minimum two frames per cycle
2. The slaves process the data twice: on the way out and on the way back
3. IP data is inserted in gaps between the frames
4. Very rigid frame layout – no changes at runtime, no bit-wise mapping.

These differences have the following impact – compared with EtherCAT:

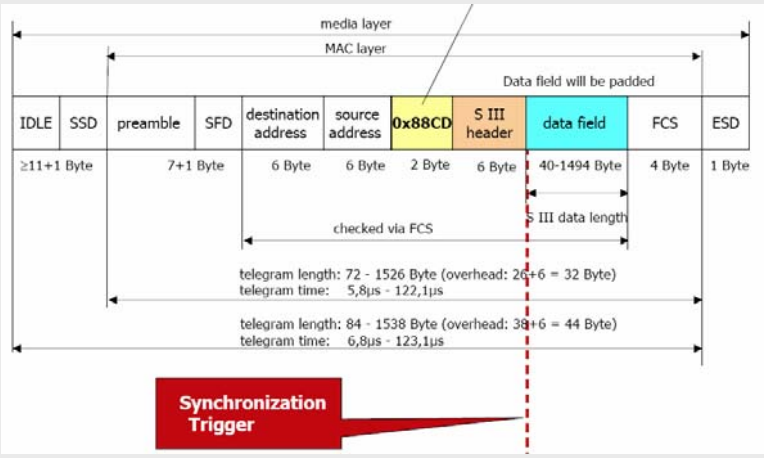
1. Bandwidth utilization is lower: especially for drives, which typically have symmetrical process images (same amount of I+O data). Therefore in average 2-3 times slower than EtherCAT.
2. Separating input and output data and processing twice allows for topology independent slave-to-slave communication within the same cycle. However, since the cycle time is higher, slave-to-slave performance is not better than with EtherCAT, which may need two cycles (depending on topology).
3. Since gaps for maximum size frames have to be kept – even if there is no IP communication present (which is the case in >99,99% of the cycles, since IP is not used for cyclic communication) – this further deteriorates bandwidth usage
4. Due to the „processing twice“ principle, only line topology (+ ring for redundancy) are possible: no drop lines, tree configuration etc.
5. No flexibility in process data communication: same update rate for all nodes and data



SERCOS III Synchronization

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

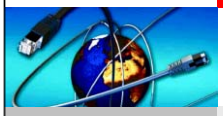


Synchronization Accuracy depends on Master Accuracy: hardware support required

Source: Presentation at Automation Summit, Beijing, June 2007

Just like with SERCOS-II, synchronization in SERCOS-III is based on cyclic, deterministic and jitter-free communication. This requires special hardware support in the master: a special dedicated SERCOS master card.

IEEE1588 support may be added later, but will as well need hw support for accuracy.



SERCOS III Synchronization

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
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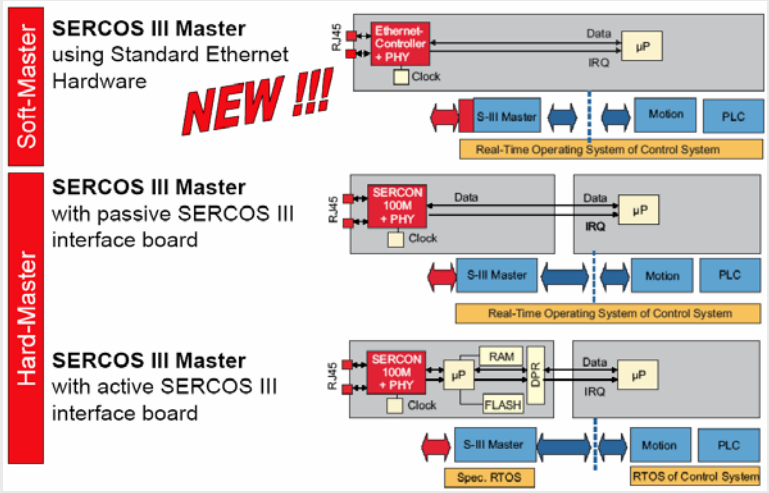
- SERCOS III
- EtherCAT
- Summary

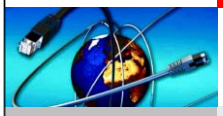


Announced in April 2007:
Soft-Master, suitable if RTOS-Jitter is sufficient for Node Synchronization

Source: Presentation at Automation Summit, Beijing, June 2007

In April 2007, Sercos International announced the development of a Sercos-III “Soft-Master”, implementing the master functionality using software (+ a standard Ethernet Port). According to the press release (quote), ”The achievable synchronization accuracy of a SERCOS III real-time network using a soft master is depending on the performance of the hardware and the characteristic of the used operating system”.

This means that e.g. with PC hardware and RTOS a synchronization accuracy of several µs seems to be achievable. For hard real time requirements, Sercos recommends the hardware implementation of the master.



SERCOS III Implementation

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

1. FPGA solution

2. Integrating SERCOS III interface into universal communication controllers
   - Cost effective
   - Makes “single-chip devices” possible
   - Multi-Protocol capability

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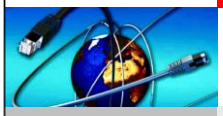
SERCOS-III Controllers are FPGA based. Later a hardcopy version may be added.

In order to push the adoption of the SERCOS I/O profile (which was published in Nov 2006), Sercos launched Easy-I/O in April 2007), a free IP Core for the Xilinx Spartan-3 XC3S250E FPGA. This code is limited to 64 Byte I/O data, and targeted at encoders, measuring sensors, valve clusters, 24V digital I/O and analog I/O. it is not suitable for Sercos-III drive implementation.

Alternatively the Hilscher netX chip can be used, which also supports EtherCAT + Profinet



SERCOS III Performance Overview

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

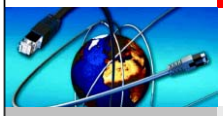
Cyclic data	Cycle time	No. of devices (1)	No. of devices (2)	MDT / AT
8 Byte	31,25 us	8		1/1
12 Byte	62,5 us	16		1/1
16 Byte	125 us	30		1/1
12 Byte	250 us	67	33	1/1
32 Byte	250 us	35	18	1/1
12 Byte	500 us	130	100	2/2
50 Byte	1 ms	100	85	4/4
32 Byte	1 ms	140	120	4/4
12 Byte	1 ms	254	220	4/4

1) without IP channel

2) with IP channel (125 µs)

Source: Presentation at Real Time Ethernet Seminar, Reutlingen, March 2005

This performance data was published in March 2005. At cycle times below 250µs there is no IP channel and thus no TCP/IP support.



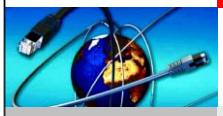
SERCOS III Performance Comparison

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

No. of Nodes with given Cycle Time			SERCOS-III		EtherCAT	
Appli-cation Example	Cyclic Data (I+O)	Cycle Time	No. of Devices without IP channel	No. of Devices with IP Channel	No. of Devices with IP	remaining Bandwidth for IP
1	8 Byte	31,25 µs	8		20	48,1%
2	12 Byte	62,5 µs	16		40	32,3%
3	16 Byte	125 µs	30		72	22,3%
4	12 Byte	250 µs	67	33	180	25,8%
5	32 Byte	250 µs	35	18	80	12,2%
6	12 Byte	500 µs	130	100	400	20,6%
7	50 Byte	1 ms	100	85	225	6,4%
8	32 Byte	1 ms	140	120	340	9,1%
9	12 Byte	1 ms	254	220	800	19,8%

Comparing SERCOS-III and EtherCAT performance: at given cycle times and amount of data per slave, the maximum number of nodes is given for both technologies. Please note that even at the shortest cycle times (and with many more nodes than the corresponding SERCOS-III network), EtherCAT still supports IP communication.



SERCOS III Performance Comparison

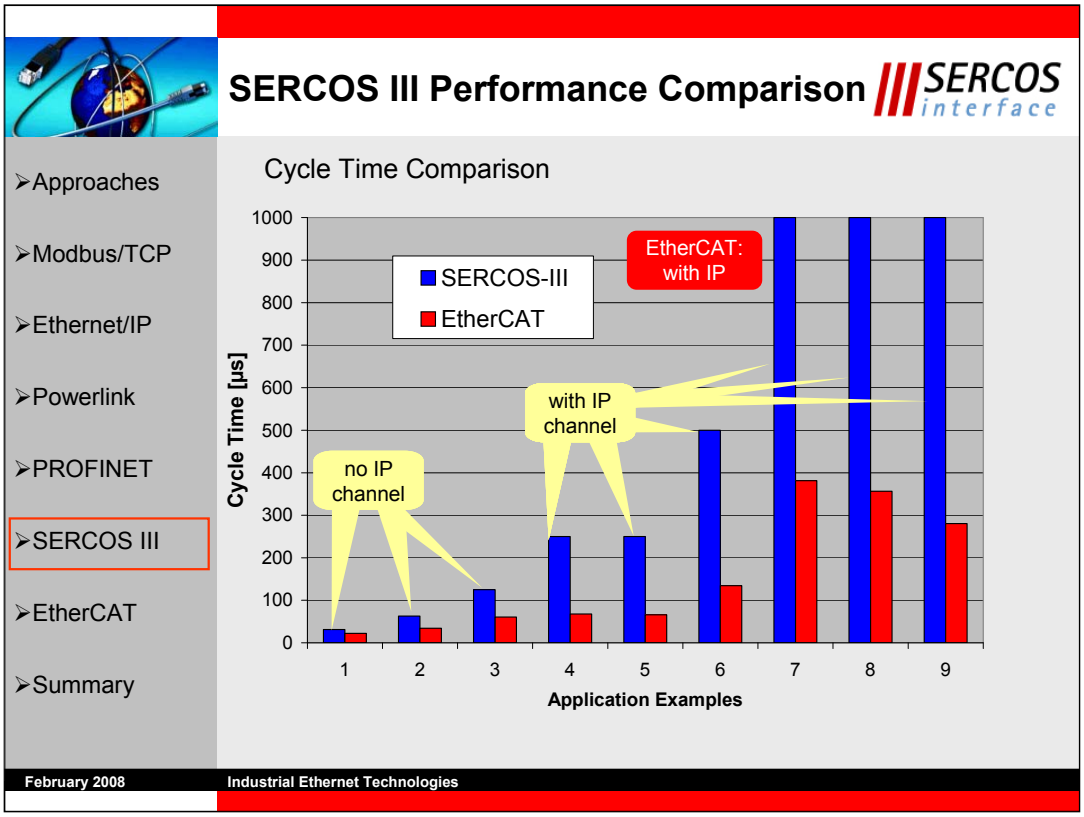
SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

Cycle Time with given No. of Nodes

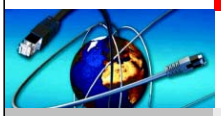
Appli-cation Example	Cyclic Data (I+O)	Cycle Time	SERCOS-III: No. of Devices without IP channel	SERCOS-III: No. of Devices with IP Channel	EtherCAT: No. of Devices with IP	EtherCAT: Resulting Cycle Time
1	8 Byte	31,25 µs	8		8	23 µs
2	12 Byte	62,5 µs	16		16	36 µs
3	16 Byte	125 µs	30		30	61 µs
4	12 Byte	250 µs	67	33	33	58 µs
5	32 Byte	250 µs	35	18	18	66 µs
6	12 Byte	500 µs	130	100	100	135 µs
7	50 Byte	1 ms	100	85	85	382 µs
8	32 Byte	1 ms	140	120	120	357 µs
9	12 Byte	1 ms	254	220	220	281 µs

Another view for the comparison: now the number of nodes and the amount of data per slave is fixed, and the resulting cycle time is compared.



A graphical view for the previous table.

In average (over 9 different application scenarios), EtherCAT is 2,9 times faster.

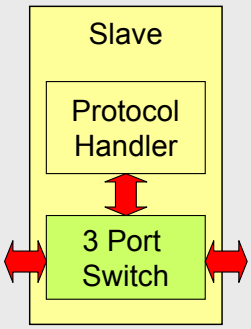


SERCOS III IP-Handling (I)

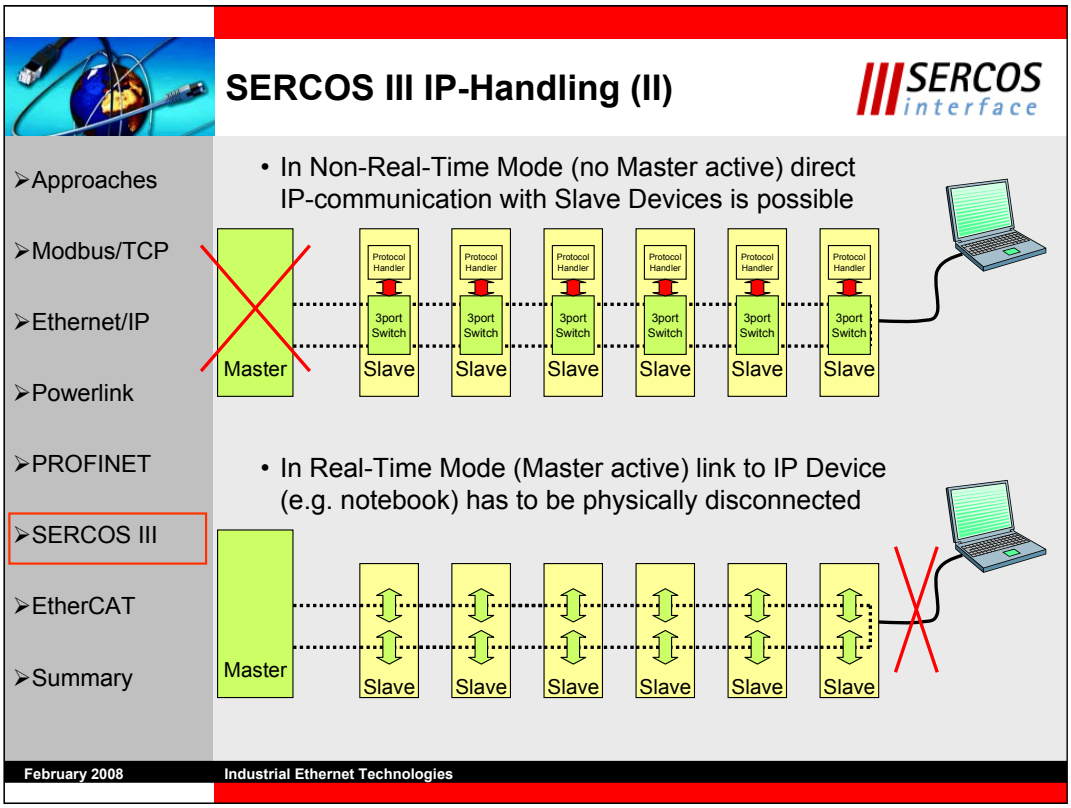
SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- At Boot-Up, Slaves are in NRT (Non Real Time) Mode until they see first RT Frame
- In NRT Mode, Slave Chips behave like 3-port Switches
- Each node needs a MAC Address
- Switch Behavior depends on Implementation:
  - Store and Forward (Default) or
  - Cut Through (High End)
- Forwarding Delay depends on No. of Nodes and on Switch Implementation
- Typical Store and Forward Delay per Node and Direction: 10…125µs, depending on Frame Length

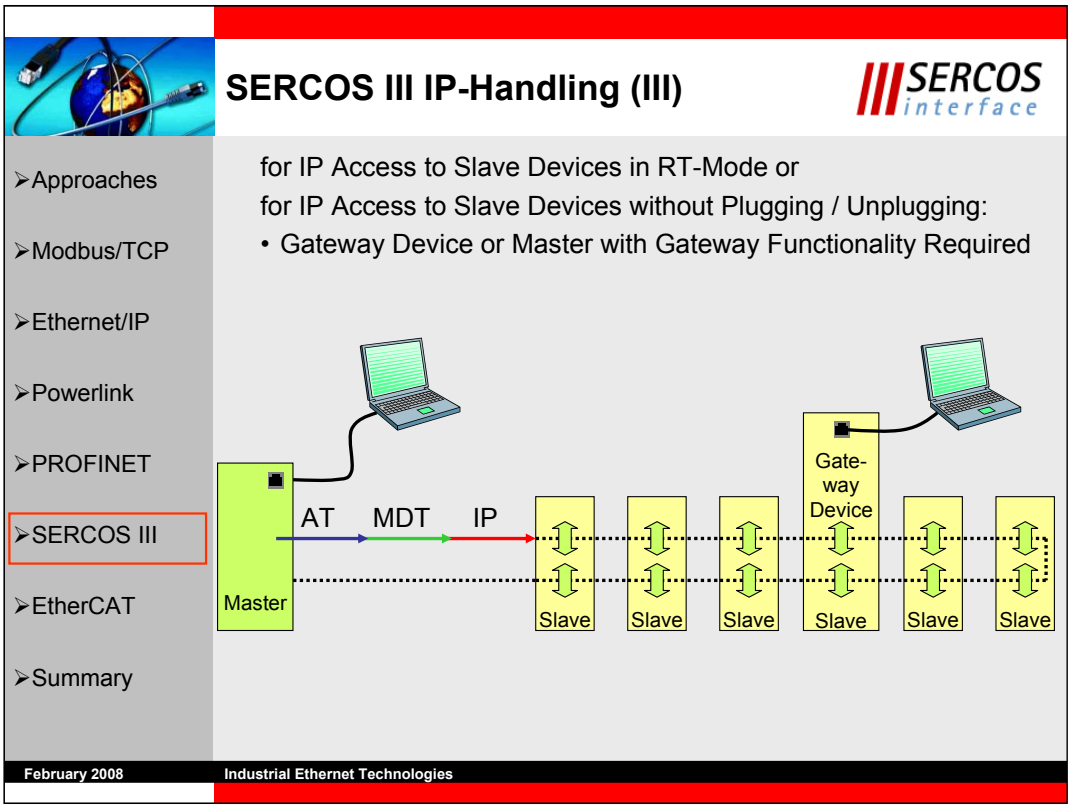


It will be interesting to see how the IP communication over a large number of cascaded switches behaves.



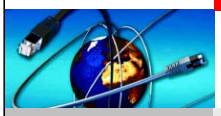
In a non-redundant network layout, the port on the last device can be used to connect a configuration notebook. However, this has to be physically disconnected before enabling the master.

There are plans to change this in a future release of Sercos-III



In order to allow for IP access to slave devices at run-time of the network, either routing through the master or a special gateway device have to be used.

This is the same if IP access (e.g. for remote diagnosis) shall be supported without the need to physically connect the link first.

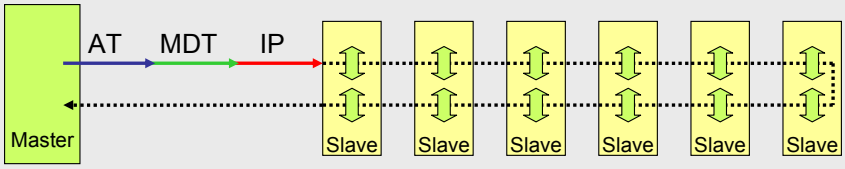


SERCOS III IP-Handling (IV)

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

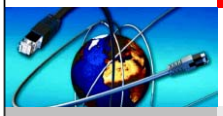
- In RT Mode, IP Traffic is inserted in IP Channel
- During IP Channel, Slave is in Switch Mode



- If IP Channel is short, Store and Forward Implementations have to delay the forwarding of larger frames to the next cycle
- Cut Through Switches can only forward frame within same cycle if >125µs IP channel is left, since frame length is unknown
- IP channel performance strongly depends on No. of Nodes, IP channel size and slave controller implementation

In each RT cycle, the slave controllers switch between “processing on the fly-mode” for process data and “switch-mode” for IP data.

The forwarding behavior of IP frames in the IP slot depends on the slave device capabilities and on the network configuration



SERCOS III V1.1

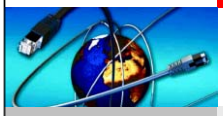
SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- In July 2007, SERCOS International released the 1.1 version of the SERCOS-III specification
- Main changes are:
  - Device addressing changed, now topology dependent
  - Parameter addressing changed from 16-bit IDN to 32-bit structured EIDN
  - status + control word format and content changed
  - Redundancy and hot-plug features introduced
  - Communication model changed from master/slave to connection oriented -
  - 511 instead of 254 slave devices supported
  - Mandatory IP channel introduced
  - Interrupt handling changed, now one Sync-IRQ
- The specification changes require hardware adaptations (Sercos controllers) and also major software changes.
- Version 1.0 and Version 1.1 devices are not interoperable
- First SERCOS-III V1.1 drives were shipped in Dec 2007.

This means that, as of beginning of 2008, Sercos-III field deployment and application experience starts all over again.

On the other hand, since hardly any Sercos-III devices were shipped before 2008, this may not be a major problem.



SERCOS III Summary

SERCOS interface

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- High Performance Industrial Ethernet Approach
- Focus on drives, so far very limited I/O, sensor, valve etc. support
- Topology: line and ring only, no branches, no drop lines, no hot connect of segments, not more than 254 nodes
- Technology is hardly field proven yet: less than 1000 nodes deployed (4/2007)
- Requires dedicated master-card for hard real time
- Use of Internet Technologies requires Cycle Times > 250µs
- Depending on configuration IP traffic can be slow

- Has been the approach that is the latest on the market
- Slow adoption rate (few Sercos I/II vendors move to Sercos III)
- EtherCAT supports the same device profile + application layer

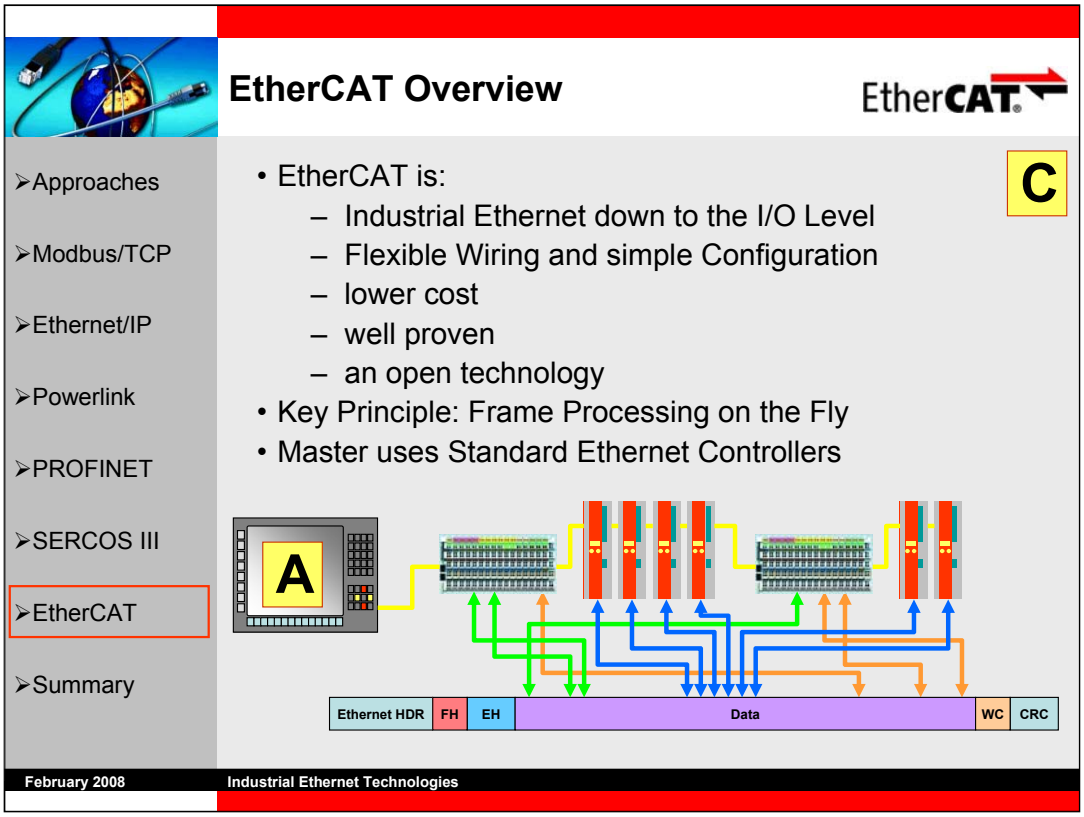
SERCOS-III achieves a performance comparable with Profinet IRT – and thus sufficient for most applications.

Whilst the SERCOS technology has a good reputation for servo drive control, support for I/O, sensors, or other devices is not yet established.

Slow adoption rate: The Sercos Product Guide of May 2007 (still online in Jan 2008) does not list Sercos-III products yet, the only Sercos III drives seen in function on trade shows so far are by Bosch Rexroth (the multi vendor demos incorporate Sercos I/II drives by other manufacturers). According to market survey published in August 2007 two companies supported Sercos-III drives: AMK and Bosch Rexroth. In a presentation held on Oct 30, 2007, Sercos International lists 4 suppliers of Sercos-III drives: AMK, Baumüller, Lust, Bosch Rexroth. AMK, Baumüller, Lust have EtherCAT drives available, Bosch Rexroth has announced EtherCAT drives in a press release published on Oct 5, 2007.

At SPS/IPC/Drives 2007, Elau announced to support Sercos-III.

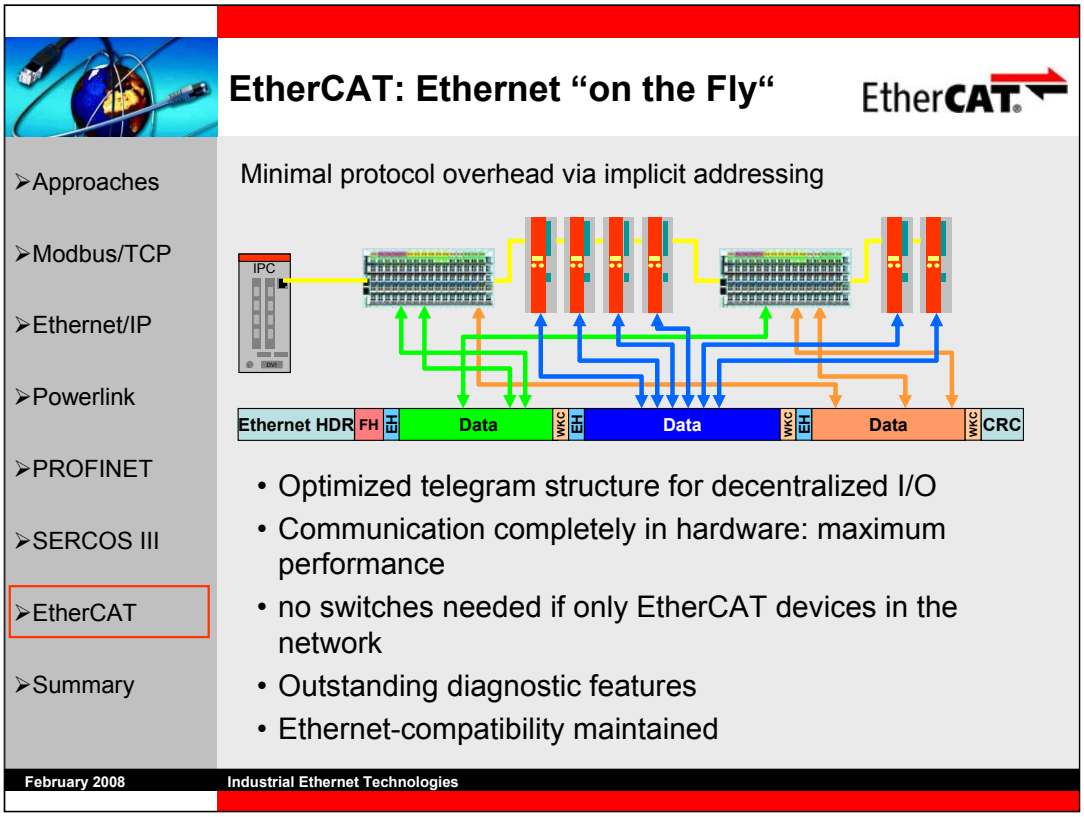
By the way: out of the 28 Sercos-I/II servo drive suppliers that are listed in the Sercos Product guide, 21 are ETG members, 14 have already shown EtherCAT drives, and 5 more have purchased EtherCAT implementation kits and attended implementation training classes (as of Dec 2007)



The Slave implementation of EtherCAT is a class C approach: the „processing on the fly“ technology requires dedicated slave controllers.

The slave controllers can be implemented as FPGA or ASIC – both solutions undercut the cost levels of the other technologies discussed in this presentation. It is not required to buy an ASIC, and there will be several sources both for FPGA and ASIC implementations.

On the master side, EtherCAT does not require a dedicated master card: any standard Ethernet Controller is sufficient, the master functionality is implemented in software running on the host CPU that also runs the application program. It was found that the master code adds less load on the host CPU than servicing the DPRAM of an intelligent plug in card.



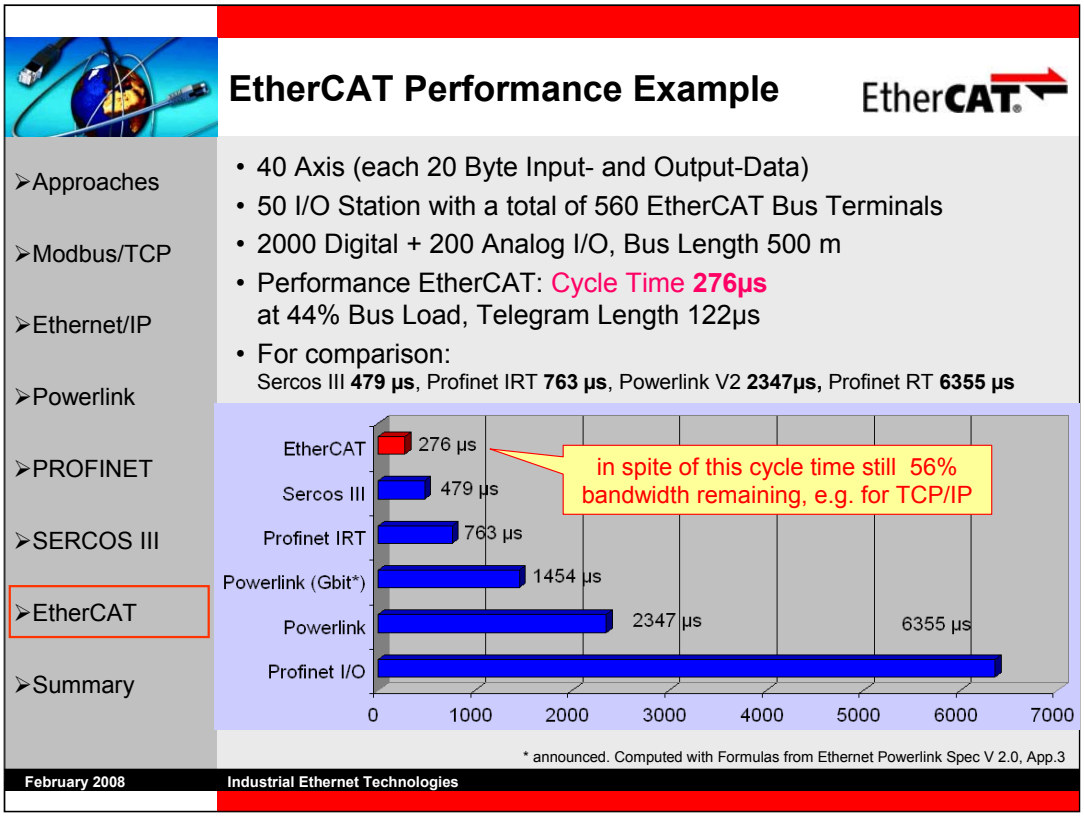
EtherCAT is very effective even with small amounts of data per slave device, since it is not necessary to send an individual Ethernet frame for each data unit.

Since process data communication is handled completely in hardware (EtherCAT Slave Controller), the network performance does not depend on the µC performance of the slave devices – and is thus predictable. This is not necessarily the case with Profinet, Ethernet/IP, Modbus/TCP and Powerlink.

Switches are optional. Thus there are no costs related to switches, their power supply, mounting, wiring, configuration and so on.

Since the CRC is checked by each device - regardless if the frame is intended for this node – bit errors are not only detected immediately, but can be also located exactly by checking the error counters.

The EtherCAT approach is still Ethernet compatible: in the master commercially off the shelf Ethernet MACs are sufficient, since only standard Ethernet frames are used.



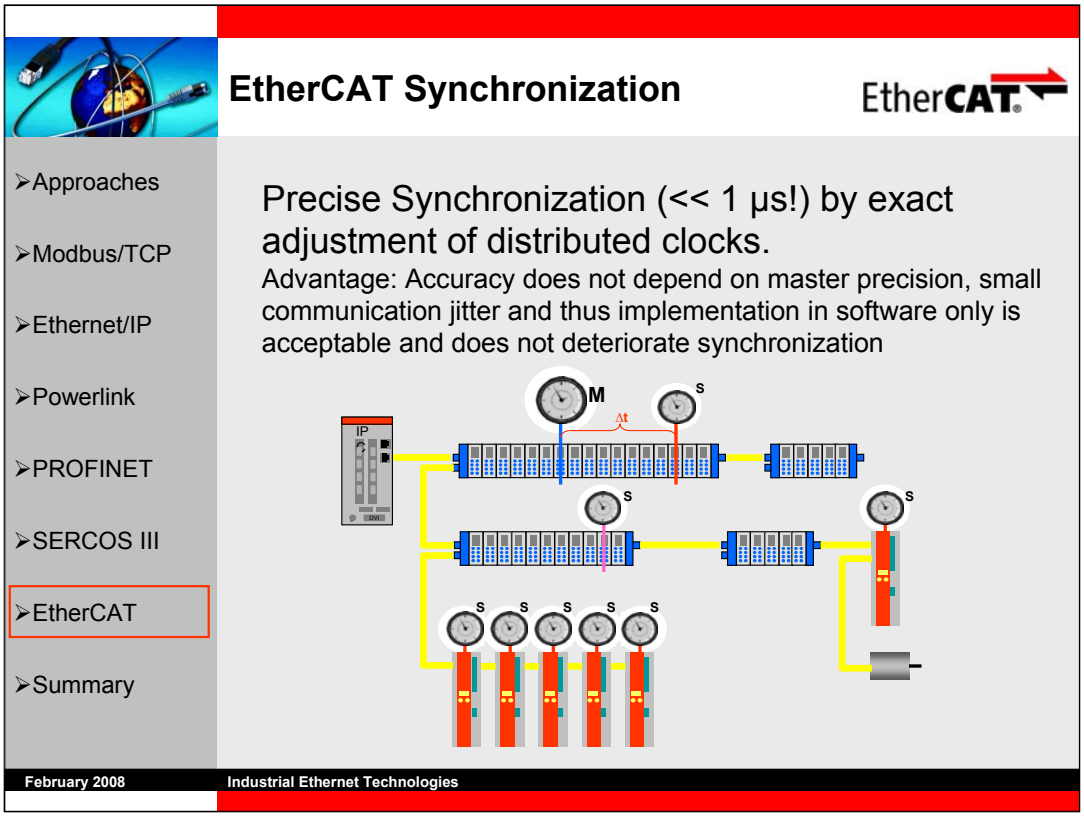
The cycle time figures of the competing technologies were determined as follows:

Profinet: Computations based on the specification (done by a well known Profinet expert). The *configurable* cycle time for this example would be 1ms (IRT) resp. 8ms (RT).

Powerlink: the network example used can be found in the annex of the Powerlink spec. With Powerlink at this cycle time there is no remaining bandwidth for asynchronous communication.

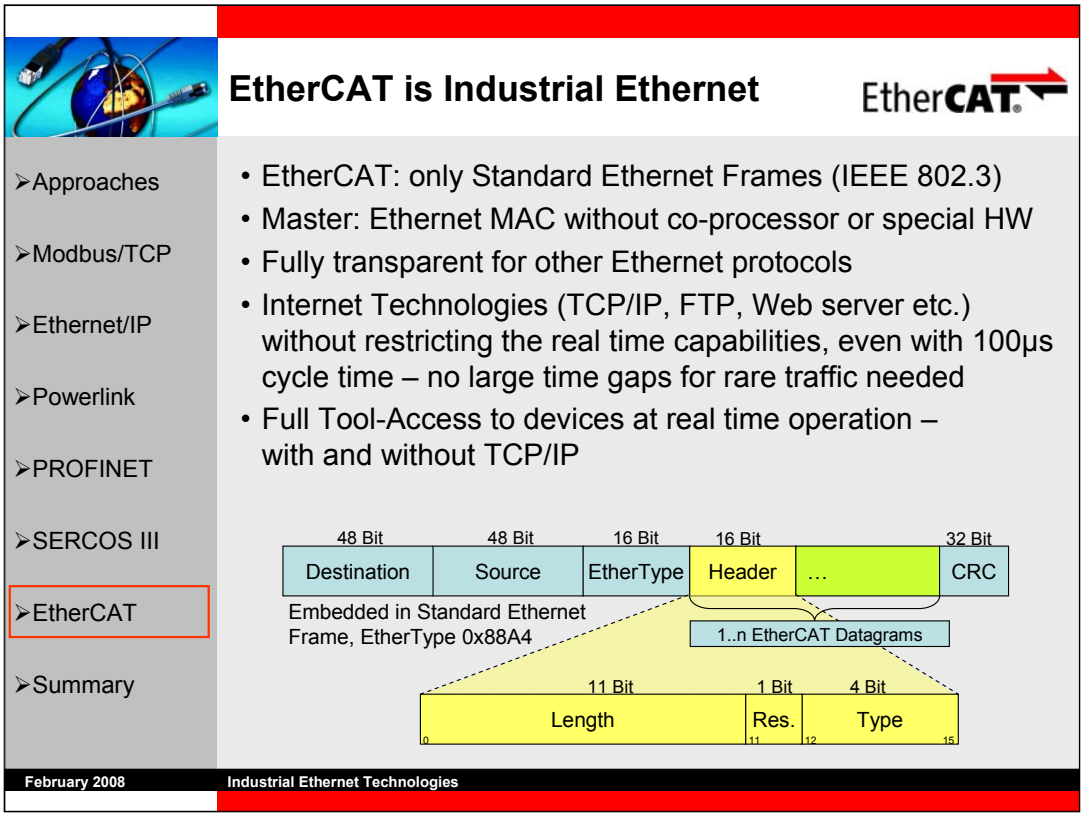
For EtherCAT the Update Time (276 µs) is given: after this period of time all outout data and all input data was transferred from or to the master – an entire cycle was finished. The telegram time is only 122µs – thus one could communicate even faster (new data every 122µs).

The Sercos-III cycle time for this example would be similar to the one of Profinet IRT.



Since EtherCAT used precisely adjusted distributed clocks (a feature of the EtherCAT Slave Controller chips), the communication cycle itself does not have to be absolutely equidistant – a small jitter is allowed. Therefore EtherCAT masters do not need a special hardware (like a communication co-processor) and can be implemented in software, only – all that is needed is an Ethernet MAC, like the one that comes with most PC motherboards anyhow.

Measurements showed a synchronization accuracy of ~20ns with 300 distributed nodes and 120m (350 ft) cable length. Since the maximum jitter depends on many boundary conditions (e.g. no. of nodes, network length, temperature changes etc.), its value is given conservatively with << 1µs.



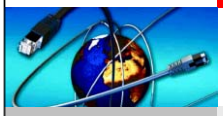
EtherCAT used only standard frames. Any other Ethernet Protocols are tunneled fully transparently – EtherCAT thus uses a method that is common with Ethernet itself and with many Internet technologies: every modem tunnels Ethernet frames as does WLAN. VPN uses this approach as does TCP/IP itself.

By using this approach EtherCAT can transport any Ethernet protocol (not ony TCP/IP) at shortest cycle times (even if they are shorter than the longest possible Ethernet frame).

In addition, it is not necessary to keep a large gap in the data stream – like other approaches have to.

The protocol used is named “Ethernet over EtherCAT”.

Many EtherCAT masters support tool access from outside: a tool can communicate via Ethernet e.g. by UDP/IP with the master, who inserts this data into the EtherCAT communication in such a way, that a fully transparent access to EtherCAT devices is possible without restricting the real time capabilities.

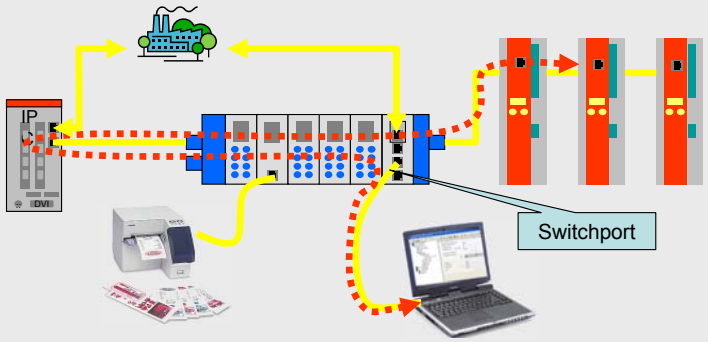


EtherCAT is Industrial Ethernet

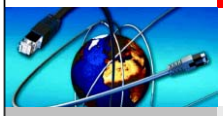
EtherCAT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Connection to any Ethernet device via Switchport
- Access to web server with standard browser
- Switchport can be implemented as device feature, seperate device or software functionality in master
- Switchport allows for hard real time capability with parallel Ethernet communication of any kind



The “tunnel entrance” (Switchport) for any Ethernet protocol can be implemented in a variety of ways: as separate device, as feature of a slave device or as software feature of the EtherCAT master.

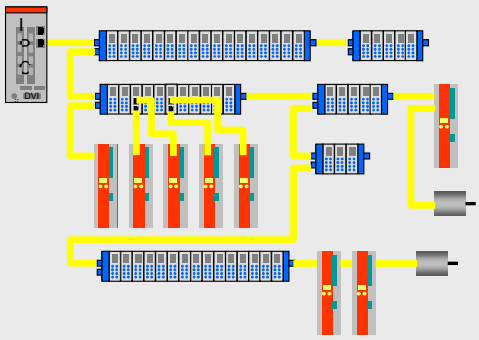


EtherCAT: Most flexible Topology

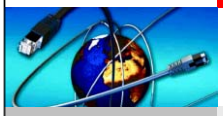
EtherCAT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Flexible tree structures – arbitrarily extendable
- Line without limitations through cascaded switches or hubs
- 100 m between two nodes, up to 65535 nodes in one segment
- branches can be connected/removed at run time (“Hot Connect”)
- Straight or crossed cables – automatic detection



With EtherCAT almost any number of devices (up to 65535) can be wired in a line structure – there are no restrictions due to cascaded switches or hubs. Any number of drop lines or branches are possible, too, providing the most flexible topology.

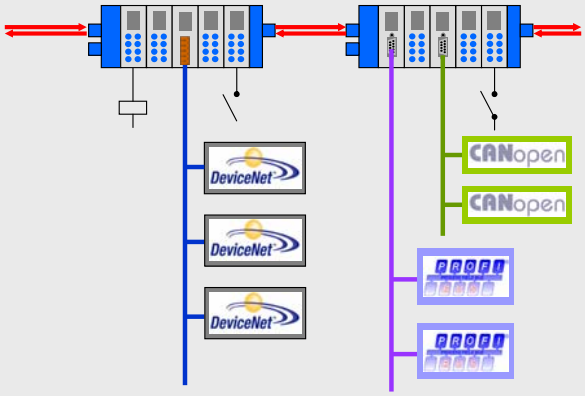


EtherCAT Gateways

EtherCAT

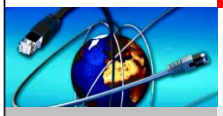
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- EtherCAT Performance allows for: EtherCAT instead of PCI
- no card slots required any more
- maximum system expandability with low cost fieldbus gateways
- seamless integration of fieldbus devices protects your investment
- smooth migration path from fieldbus to EtherCAT



EtherCAT is so fast that it can replace the PCI bus (and thus the PCI slots) in almost all applications. Fieldbus master and slave card can be moved into the EtherCAT network. EtherCAT control computers can thus be very compact, without restricting the expandability.

In addition, this feature provides a very elegant and smooth migration path: Devices which are not (yet) available with EtherCAT interface, can be integrated via underlying fieldbus systems – typically without restricting the performance compared with the PCI solution.



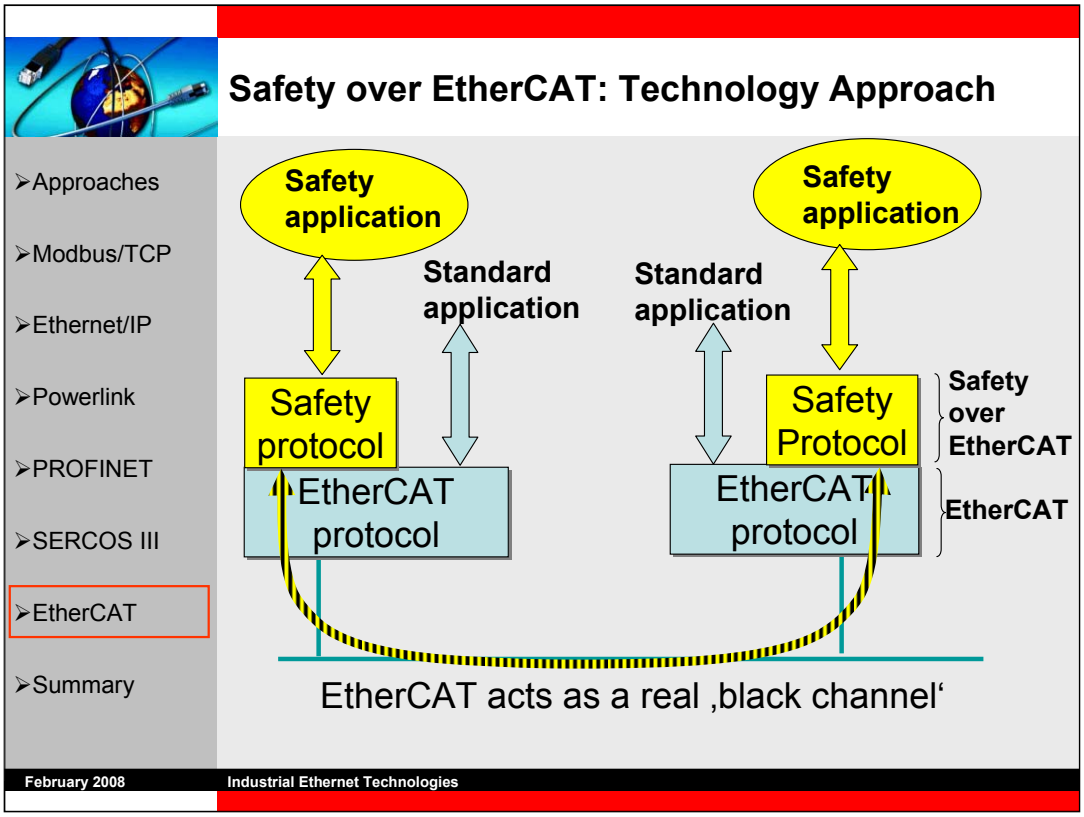
Safety over EtherCAT: Features

EtherCAT

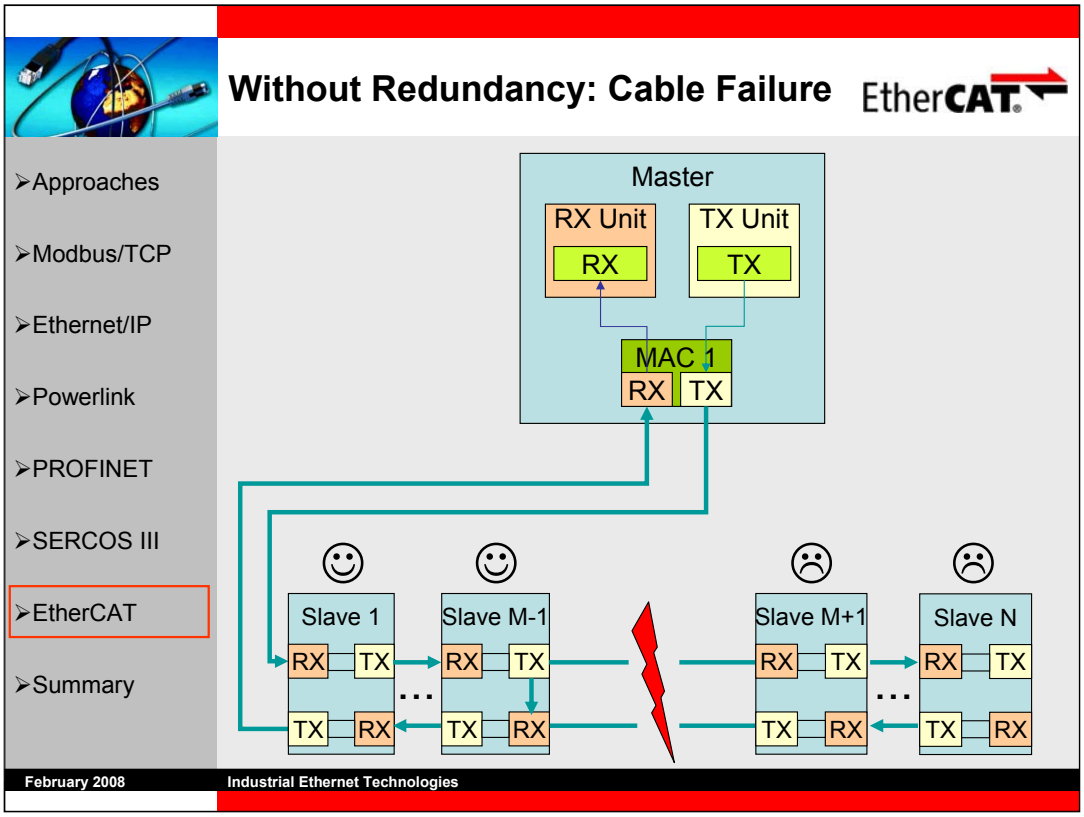
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- TÜV certified technology
- Developed according to IEC 61508
- Protocol meets Safety Integrated Level (SIL) 4
- Device implementations typically SIL 3
- Suitable for functional safe I/O as well as for functional safe motion control
- Variable CRC size for minimal overhead
- Safe Parameter Download at boot-up: most simple device exchange possible
- Safety devices available since end of 2005

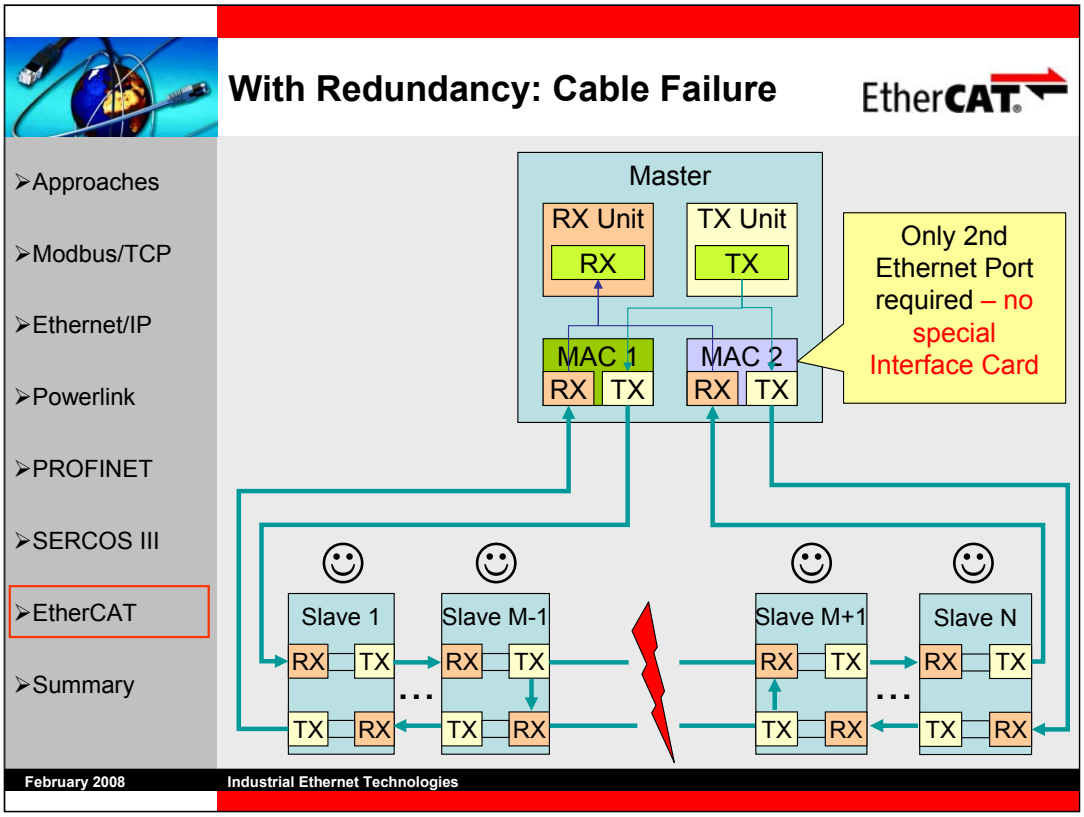
The error probability of the Safety over EtherCAT protocol is low enough, that the protocol itself meets SIL 4 requirements. However, devices implementing this protocol typically meet SIL 3 – and thus KAT 4 of EN 954-1.



With Safety over EtherCAT the communication channel is really “black” (or irrelevant for the safety analysis), and not “grey”. Therefore e.g. no SIL monitor is required to check the current error rate on the network.



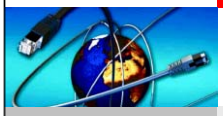
EtherCAT is – even when wired in line topology – a ring structure, with two channels in one cable (Ethernet full duplex feature). Whilst device located before a cable or device failure can continue to operate (the EtherCAT Slave Controller closes the ring automatically), devices behind the cable failure are naturally not accessible any more.



If the line is turned into a ring, there are two communication paths to each device: redundancy.

With EtherCAT even without special hardware in the master: a second Ethernet port is sufficient.

By using this device exchange at run time (hot swap) is feasible as well.



EtherCAT is simpler to configure

EtherCAT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

Addressing:

- No manual address setting required
- Addresses can be kept – no new addressing if nodes are added

Topology:

- Automatic topology target/actual comparison possible

Diagnosis:

- Diagnosis information with exact localization

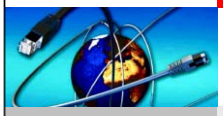
Network planning:

- Performance independent of slave implementation (e.g. stack features, µC performance)
- Performance widely independent from topology (no switches/hubs)
- Performance more than sufficient - therefore no „tuning“ required any more, default settings do the job

The configuration of an EtherCAT network is very simple.

This is in particular the case for the network planning: since the process data performance does not depend on the devices that were selected (and their µC and stack performance) and since the topology has almost no influence at all, hardly anything has to be considered.

Also the network tuning, which has been necessary with many fieldbus and industrial Ethernet solutions, is hardly needed at all: even with default settings Ethernet is more than fast enough.



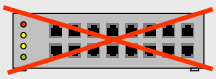
EtherCAT is lower costs

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

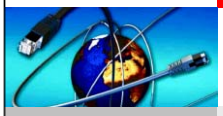
Master:
no dedicated plug in card (co-processor),
on-board Ethernet Port is fine

Slave:
- low cost Slave Controller
- FPGA or ASIC
- no powerful µC needed

Infrastructure:
- no Switches/Hubs required
- Standard Ethernet Cabling



EtherCAT intends to even undercut the fieldbus cost levels – in spite of a performance, that is much better and many additional features.



EtherCAT: open technology

EtherCAT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- Protocol is published completely:
- EtherCAT is IEC standard (IEC 61158, IEC 61784-2, IEC 61800-, ISO standard (ISO 15745-4) and SEMI standard (E54.20)
- Slave Controllers from several suppliers
- Master Stacks from several suppliers (also open source)
- Supported by the EtherCAT Technology Group
- Foundation: November 2003
- Tasks: Support, Advancement and Promotion of EtherCAT
- Already more than 670* member companies from 37 countries in 6 Continents:
  - Device Manufacturers
  - End Users
  - Technology-Provider
- ETG Offices in Germany, USA, China, Japan and Korea
- Membership is open to everybody

EtherCAT Technology Group

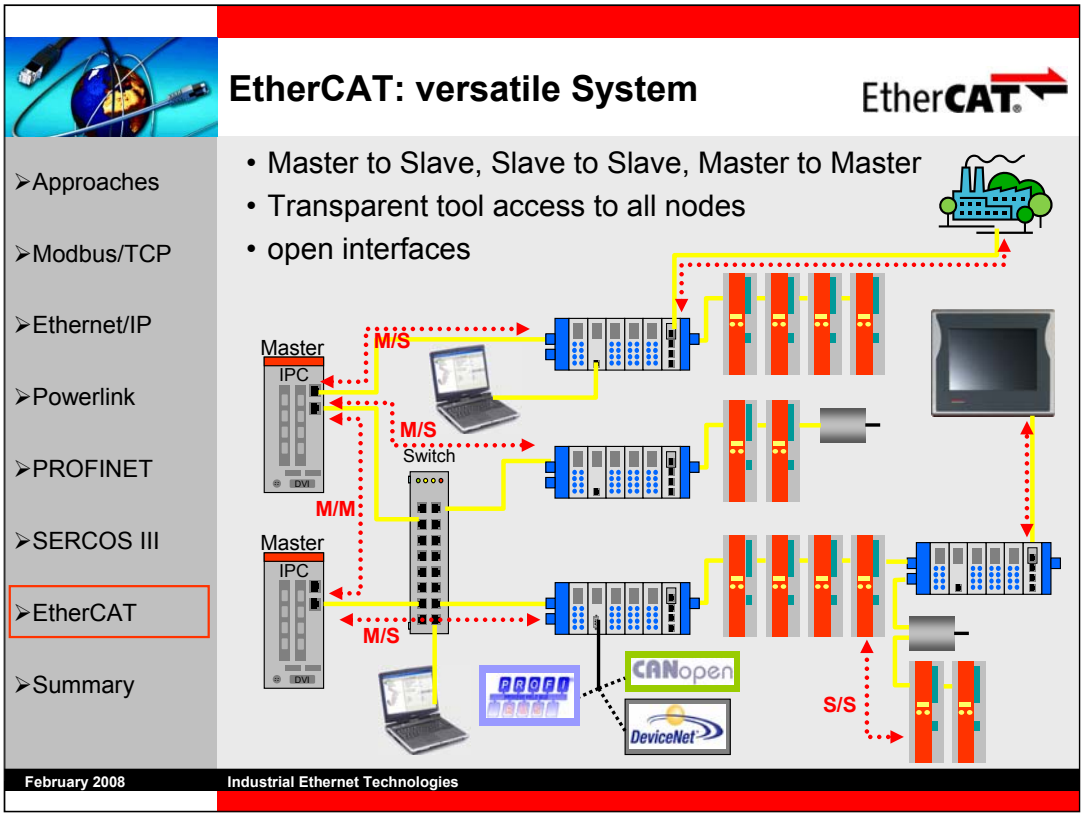
* as of Jan 2008

The EtherCAT Technology Group is official standardization partner of the IEC: the ETG nominates experts for the international standardization committees and may submit standard proposals.

Since beginning of 2005 EtherCAT is an official IEC specification: IEC/PAS (Publicly Available Specification) 62407, which can be obtained from the IEC webstore. Since Oct. 2007 EtherCAT is part of the standards IEC 61158 (Digital data communication for measurement and control – Fieldbus for use in industrial control systems), IEC 61784-2 (Digital data communication for measurement and control –Part 2: Additional profiles for ISO/IEC 8802-3-based communication networks in real-time applications) and IEC 61800-7 (Profiles for motion control systems). The latter is particularly important for motion control applications, since it makes EtherCAT a standardized communication technology for the SERCOS and CANopen drive profiles, on an equal footing with SERCOS I-III and CANopen respectively. The drive parameters and state machines as well as the process data layout of the device profiles remain untouched when mapped to EtherCAT. Hence the user interface does not change when moving from SERCOS and CANopen to EtherCAT, and device manufacturers can re-use major parts of their firmware.

EtherCAT is also part of ISO 15745-4 (device description profiles)

The EtherCAT Technology Group (ETG) is an organization in which key user companies from various industries and leading automation suppliers join forces to support, promote and advance the EtherCAT technology. With over 650 members, the EtherCAT Technology Group has become the largest organization in the world that is exclusively focused on Industrial Ethernet technologies. Founded in November 2003, it is also currently the fastest growing fieldbus organization.

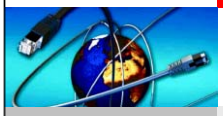


Besides the master/slave communication EtherCAT provides further possibilities: masters can communicate among each other as well as slave devices.

For slave to slave communication there are two varieties:

Topology dependent slaves can insert data “upstream” which can be read “downstream” by all other slaves. In many applications that require slave to slave communication these relationships are known at network planning stage and thus can be handled with accordingly. Wherever this is not possible, the second variant can be applied:

Topology independent two cycles are used for slave to slave communication. In most cases the corresponding delay time is not critical at all – in particular if one considers that EtherCAT is even at twice the cycle time still faster than any other solution….



EtherCAT Summary

EtherCAT

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

- EtherCAT provides:
  - Superior Performance
  - Line, Ring, Tree, Drop Line, Star Topology
  - Master/Slave, Master/Master and Slave/Slave communication
  - Integrated Functional Safety: Safety over EtherCAT
  - TCP/IP without cycle time limitations
  - Simple configuration – no manual address setting
  - Comprehensive diagnosis functionality
  - Redundancy
  - Support of CANopen and SERCOS* Drive Profiles
- EtherCAT is:
  - Open technology, worldwide supported, IEC standard
  - Low cost and simple to implement

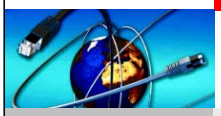
*SERCOS interface™ is a trademark of SI e.V.

EtherCAT typically is chosen for one or more of these three reasons:

- superior performance
- flexible topology – even at large distances
- low costs

For more information regarding EtherCAT please go to

www.ethercat.org



RTE Technology Comparison

- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

Performance	Modbus/ TCP	Ethernet /IP	ProfiNet RT (I/O)	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Cycle Time	--	--	-	o	+	+	++
Synchronicity	--	-- + (CIP sync)	--	+	+	+	++
Throughput of IP Data	++	++	++	o (half duplex)	+	o	+

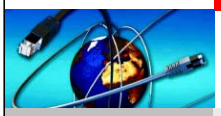
In principle, one should not compare technologies in such an overview table: since the ratings are based on figures, assumptions and assessments that cannot be given in full detail, one may come to a different conclusion. However, some like and ask for these tables.

In order to provide a better transparency, comments for each row are provided.

Cycle Time: EtherCAT is about 3 times faster than Profinet IRT and Sercos-III, and about 10-15 times faster than Powerlink. Due to TCP/IP usage for process data communication and the related stack delays, the Modbus cycle time in principle is longer than with Profinet I/O – but this is widely implementation dependent.

Synchronicity: The EtherCAT distributed clock mechanism provides jitter-values of <<1µs. With Sercos-III and Powerlink the jitter depends on the communication jitter of the master, with Profinet-IRT it depends on the number of cascaded switches. All three technologies claim a jitter of <1µs – as does CIPsync.

Throughput if IP data: with the „best effort“ approaches Modbus, Ethernet/IP and Profinet I/O the throughput of IP data is basically limited by the stack performance. Since Profinet IRT and EtherCAT reserve bandwidth for Real-time communication, the remaining throughput for IP data is reduced by the protocol – but typically it remains higher than the stack performance of an embedded TCP/IP stack. Powerlink suffers from half duplex communication and overall poor bandwidth utilization due to polling. Sercos-III suffers from the delay introduced by large no. of cascaded switches (in Realtime Mode).



RTE Technology Comparison

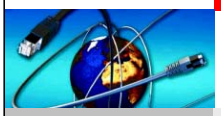
- Approaches
- Modbus/TCP
- Ethernet/IP
- Powerlink
- PROFINET
- SERCOS III
- EtherCAT
- Summary

Wiring	Modbus/ TCP	Ethernet /IP	ProfiNet RT (I/O)	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Topology Flexibility	--	--	--	+	+	o	++
Line Structure	--	--	--	o (10)	o (25)	+ (254)	++ (65535)
COTS Infrastructure Components (Switch, Router, Connector etc.)	++	+	++	o (no Switch)	--	-	+

Topology Flexibility: EtherCAT supports line, tree, star, ring, drop lines without practical limitations on number of nodes and hardly any influence on performance. Sercos-III: line and ring only. Profinet IRT: line, tree, star, drop lines, but limited no. of nodes and strong interdependency between topology and performance. Powerlink: line, tree, star, drop lines, but strong limitation due to hub delays.

Line Structure: ModbusTCP, Ethernet/IP + Profinet I/O do not support line topology. With Powerlink, only few nodes in line, due to hub delays. According to B&R user manual, a maximum of 10 hubs is allowed between master and slave – so only 10 nodes in line. With Profinet IRT, accumulated jitter due to cascaded switches limits the no. of nodes in line topology to 20. Sercos-III specifies up to 254 nodes in line, EtherCAT supports up to 65535.

Commercially Off The Shelf (COTS) Infrastructure Components: Ethernet/IP asks for manageable switches with IGMP support. Hubs with 100 MBit/s (Powerlink) cannot be considered COTS technology, since the chips are obsolete. Profinet IRT requires special switches throughout, Sercos-III does not allow switches, EtherCAT can be used with switches (between masters and EtherCAT segments). If required, EtherCAT networks can be further extended e.g. by inserting fiber optic segments using standard infrastructure devices.



RTE Technology Comparison

- Approaches
- Modbus/TCP
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- PROFINET
- SERCOS III
- EtherCAT
- Summary

Features	Modbus/ TCP	Ethernet /IP	ProfiNet RT (I/O)	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Slave to Slave Communication	✔	✔	✔	✔	✔	✔	✔
TCP/IP & other Internet Technologies supported	✔	✔	✔	✔	✔	✔	✔
Cable Redundancy	(switches with spanning tree)	(switches with spanning tree)	(switches with spanning tree)	?	o*	✔	✔
Safety	-	✔	✔	✔	✔	✔	✔

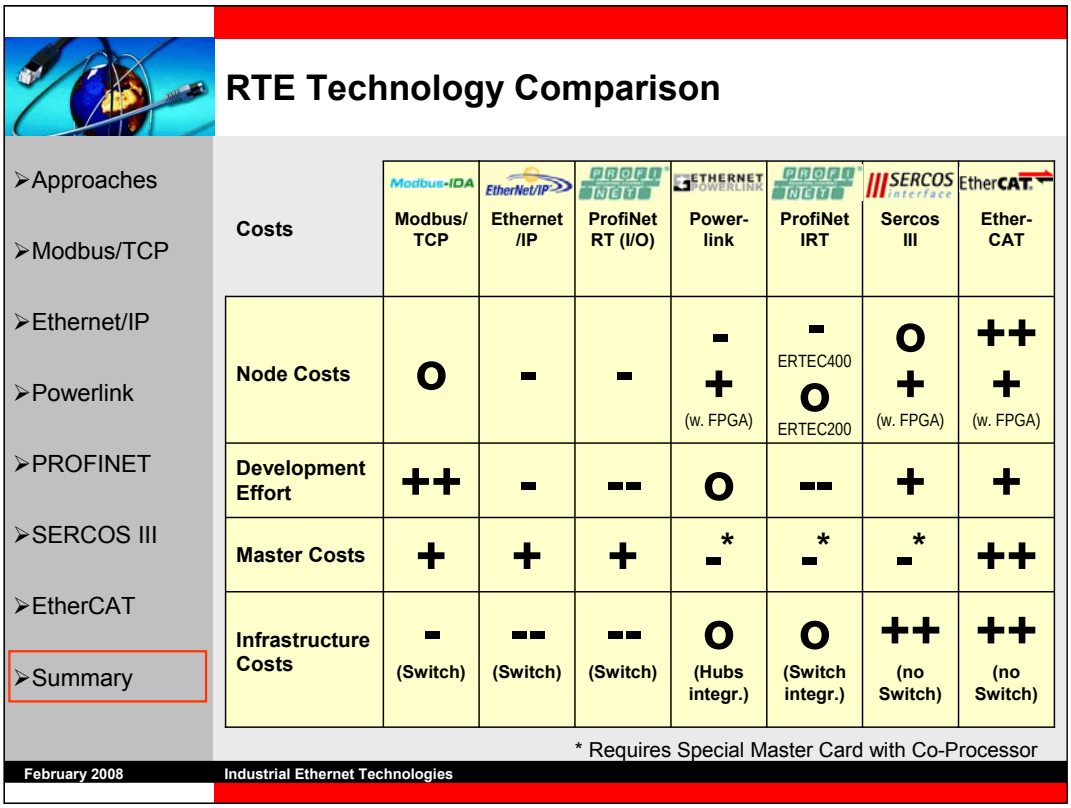
* planning algorithm extremely complex, no known approach

Slave to Slave Communication: supported by all technologies. Via Master only: Modbus/TCP. Directly between slaves, but initiated by master: all others (EtherCAT: depending on topology). Topology independent slave-to-slave communication with EtherCAT requires 2 cycles, so performance of this communication type may be degraded to Sercos-III or Profinet IRT levels.

TCP/IP & other Internet Technologies supported: all technologies allow for TCP/IP communication and Internet Technologies. Modbus/TCP, Ethernet/IP and Profinet I/O have no scheduling for this communication, all others do. Powerlink + Sercos-III connect generic Ethernet devices (e.g. Service notebooks) via Gateways, Profinet-IRT and EtherCAT via special switchports.

Cable Redundancy: For Modbus/TCP, Ethernet/IP and Profinet I/O switches with spanning tree protocol can be used to establish cable redundancy (between the switches only). For Powerlink, a redundancy option has been announced (solution and effort unclear). Profinet IRT aims for redundancy, but the planning algorithm for a redundant IRT topology is so complex that its implementation is questionable. Sercos-III and EtherCAT support cabling redundancy, for EtherCAT with very little additional hw effort (only a 2nd Ethernet port in the master, no special card).

Safety: There is no known safety protocol for Modbus/TCP. The safety approaches of the other technologies differ regarding availability: Safety over EtherCAT products are shipping since end of 2005.



RTE Technology Comparison

- Approaches
- Modbus/TCP
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Costs	Modbus/ TCP	Ethernet /IP	ProfiNet RT (I/O)	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Node Costs	o	-	-	- + (w. FPGA)	- ERTEC400 o ERTEC200	o + (w. FPGA)	++ + (w. FPGA)
Development Effort	++	-	--	o	--	+	+
Master Costs	+	+	+	-*	-*	-*	++
Infrastructure Costs	- (Switch)	-- (Switch)	-- (Switch)	o (Hubs integr.)	o (Switch integr.)	++ (no Switch)	++ (no Switch)

* Requires Special Master Card with Co-Processor

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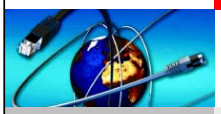
Node Costs: Whilst Modbus/TCP – due to limited real time claims – can be implemented on 16bit µC, Ethernet/IP, Profinet I/O and Powerlink require substantial processing power and memory. Using FPGAs, Powerlink, Sercos and EtherCAT achieve comparable cost levels (assuming the Sercos implementation will use similar FPGA sizes), the ASIC implementation of EtherCAT reaches or undercuts fieldbus cost levels.

Development effort: Assuming the TCP/IP stack is present, Modbus/TCP can be implemented with very low effort. Profinet I/O requires about 1 MByte (!) of code. Profinet IRT is very complex – not only but in particular the master. EtherCAT slaves can be implemented with very little effort, since all time critical functions are provided in hardware. EtherCAT masters range from very simple (e.g. with one process image) or more complex (e.g. with dynamic scheduling). Sercos development effort for slave devices is assumed to be similar to EtherCAT, since real time part is handled in hw, too.

Master Costs: Modbus/TCP, Ethernet/IP, Profinet I/O and EtherCAT masters do not require a dedicated plug in card. Since EtherCAT masters typically only send one frame per cycle, the additional CPU load on the master is much lower than with the others in this group. Powerlink, Profinet IRT and Sercos-III require special dedicated master cards with communication co-processors.

Infrastructure Costs: Whilst Modbus uses switches (but no special ones), Ethernet/IP (+ typically Profinet I/O) require manageable switches (Ethernet/IP with IGMP support). Depending on the topology, the integrated hubs (Powerlink) or special switches (Profinet-IRT) are sufficient - if not, external hubs or special switches are required. Sercos-III and EtherCAT do not require switches or any other active infrastructure components.



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Strategic Topics (I)	Modbus/ TCP	Ethernet /IP	ProfiNet RT (I/O)	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Size of supporting organization	++	+*	+*	o	+*	o	++
Worldwide User Group?	++	++	++	o	++	o	++
Time to Market	++	+	o	o (V1 / V2 issue)	- (new IRT Version in 2009)	-	+

* Not all ODVA or PTO/PNO members support Ethernet

User Group Size: No. of members in the user group is not crucial, but may serve as an indicator for the acceptance. As of October 2007, the EtherCAT Technology Group has 607 member companies, Sercos International has 40 member companies*. EPSG (Powerlink) has 66 member companies**. ODVA has 297 member companies***. PTO is much larger, but their membership is predominantly fieldbus (Profibus) related. ModbusTCP is so widely used that the Modbus IDA membership of 55 members**** only does not reflect its acceptance.

Worldwide User Group: ODVA and PTO are present worldwide – as is ETG, with offices in Europe, North America, China and Japan.

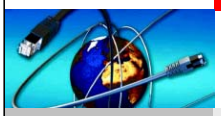
Time to Market: Modbus/TCP is available since 1999. Ethernet/IP since 2001. Profinet RT has entered the market in 2005. Powerlink V2 is not yet widely available, the B&R proprietary version 1 is shipping since end of 2002. The next generation Profinet IRT chips are expected for 2009, first Sercos-III V1.1 devices were shipped end of 2007. EtherCAT is used in series applications since end of 2003.

* according to website www.sercos.de as of Oct 2007, + 12 Sercos North America, + 15 Sercos Japan

**according to EPSG Publication “PowerlinkFACTS” published in November 2007. In April 2007, there were 71 member companies

*** according to www.odva.org as of Oct 2007

**** according to www.modbus-ida.org as of Oct 2007



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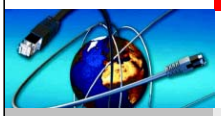
Strategic Topics (II)	Modbus/ TCP	Ethernet /IP	ProfiNet RT (I/O)	Power-link	ProfiNet IRT	Sercos III	Ether-CAT
Special Hardware used?	++	++ - (CIP Sync)	++	o (S: HUB FPGA)	- (M+S)	- (M+S)	o (S)
Proof of Technology? Pilot Applications?	++	+ - (CIP Sync)	+	+ (V1) - (V2)	o (IRT) -- (IRTV4)	o (V1) -- (V1.1)	+
International Standardization	+	+	+	+	+	+	+

Special Hardware Used: Modbus/TCP, Ethernet/IP (not: CIPsync) + Profinet I/O can be implemented with standard hardware chips. For Powerlink, the integrated hub is implemented as FPGA, since 100MBit/s hub chips are obsolete. Profinet IRT and Sercos-III requires special chips in master and slave, EtherCAT requires an EtherCAT Slave Controller (FPGA or ASIC) but no special chips, cards or co-processors in the master.

Proof of Technology, Pilot Applications: Modbus TCP has been used for many years. Ethernet/IP, Profinet I/O and EtherCAT are proven technologies, just as Powerlink V1 (and unlike Powerlink V2). First version of Profinet IRT started to ship in 2006, new version with new ASICs expected for 2009. There are few published IRT pilot applications, and according to my best knowledge most use a Siemens only protocol variant. First Sercos-III 1.0 devices start shipping in 2006, so far very few applications (in 4/ 2007 less than 1000 device were shipped). New enhanced V1.1 version (incompatible with V1) started shipping in December 2007.

International Standardization: As far as international standardization is concerned, all listed technologies can be considered to be even. Since Oct 2007, all are part of IEC 61158 and IEC 61784-2

Modbus-TCP: Communication Profile Family (CPF) 15, IEC 61158 Type 15
Ethernet/IP: CPF 2, IEC 61158 Type 2
Profinet: CPF 3, IEC 61158 Type 10
Powerlink: CPF 13, IEC 61158 Type 13
Sercos-III: CPF 16, IEC 61158 Type 19
EtherCAT: CPF 12, IEC 61158 Type 12



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